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Nonpoint Source Model Calibration in Honey Creek Watershed

Resources Management Associates, West Chester, PA

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NONPOINT SOURCE MODEL CALIBRATION IN HONEY CREEK WATERSHED

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FOREWORD

As environmental controls become more costly to implement and the penalties of judgement errors become more severe, environmental quality management requires more efficient analytical tools based on greater knowledge of the environmental phenomena to be managed. As part of this Laboratory's research on the occurrence, movement, transformation, impact, and control of environmental contaminants, the Technology Development and Applications Branch develops management or engineering tools to help pollution control officials achieve water quality goals through watershed management.

These efforts include programs to provide state-of-the-art models for analyzing agricultural nonpoint pollution and evaluate their effectiveness as land management tools. One tool to evaluate the magnitude of diffuse pollutant load reductions is the EPA Non-Point Source Model. This report applies the model to a large watershed in the Great Lakes region in an evaluation of selected best management practices.

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ABSTRACT

The U.S. EPA Non-Point Source Model has been applied and calibrated to a fairly large (187 sq. mi.) agricultural watershed in the Lake Erie drainage basin of north central Ohio. Hydrologic and chemical routing algorithms have been developed. The model is evaluated for suitability as a land management tool in estimating the reduction in sediment associated phosphorus from cultivated land. Results indicate a very different impact for selected best management practices (BMP) estimated using the Universal Soil Loss Equation (USLE) gross erosion approach. Modifications to the model structure are suggested to improve BMP evaluation.

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LIST OF ABBREVIATIONS

Abbreviation

sq. mi. -- square mile
ha. -- hectare
MSS -- multispectral scanner
D.A. -- drainage area
cfs/sq. mi. -- cubic feet per second per square mile
PE -- potential evapotransportation

METRIC CONVERSION TABLE

ENGLISH UNIT	MULTIPLIER	METRIC UNIT
acre (acre)	0.405	hectare (ha)
cubic foot (cf)	28.32	liter (l)
cubic feet per second (cfs)	28.32	liters per second (l/sec)
degree Fahrenheit (deg F)	0.555(°F-32)	degree Celsius (deg C)
feet per second (fps)	0.305	meters per second (m/sec)
foot (feet) (ft)	0.305	meter(s) (m)
gallon(s) (gal.)	3.785	liter(s) (l)
parts per million (ppm)	1.0	milligrams per liter (mg/l)
pounds per acre (lb/acre)	1.121	kilograms per hectare (ka/ha)
square foot (sq ft)	0.0929	square meter (sq m)
ton (short) (ton)	907.2	kilogram (kg)metric ton
ton per acre (tons/acre)	0.3674	metric tons per hectare (metric tons/ha)
yard	0.914	meter (m)

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This applied research on the NPS model application could not have been possible without extensive chemical sampling and analysis over a two year period by Dr. David Baker and his staff at Heidelberg College, supported in large part by the Buffalo District, U.S. Army Corps of Engineers.

SECTION 1

INTRODUCTION

The Honey Creek basin is a 187 sq. mi. tributary of the Sandusky River (1430 sq. mi.) draining from north central Ohio into the western edge of the central basin of Lake Erie. Like much of the Lake Erie direct drainage area, the physiography is glacial in origin and is characterized by flat, high water table soils which are very productive if drained. The storm runoff from similar agricultural lands around the basin is estimated to contribute about half of the annual total phosphorus input to the lake (COE, 1975). Even with projected point source reductions in phosphorus loading, it is anticipated that this agricultural non-point phosphorus load must be reduced by 35% to achieve desired water quality in the lake. Land management strategies are being evaluated, but the source areas must be defined, as well as erosion and transport mechanisms of the sediment associated phosphorus understood, to rationalize the application of feasible strategies.

One of the management tools considered to evaluate the magnitude of diffuse pollutant load reduction is the EPA Non-Point Source Model (EPA, 1976). The Honey Creek basin is substantially larger than the test plots and small catchments used for initial model development, but represents a good practical scale for watershed planning. Successful use of the model for input to decision making by the agricultural technical community and farmers will greatly enhance the selection of those tillage practices which will achieve the greatest pollutant load reduction.

The available chemical transport record at the major gage station of Melmore (D.A. 149 sq. mi.) is excellent, much better than most stream systems of this size. On the other hand, the meteorologic record does not include any well-located continuous precipitation recorders. While the rainfall record is poor by comparison to prior research applications of the NPS model, it is representative of the data availability in most watersheds of this size across the country. The combined effect of good chemistry and precipitation data should still allow satisfactory calibration of a model such as NPS, especially in terms of total mass transport estimates.

One major limitation of the NPS model is the "scale" problem, with the original equations written for small catchments and lacking stream transport and routing subroutines in its original form. For the Honey Creek application, routing from 14 subbasins which average 10 sq. mi. in size to the Melmore gage is necessary for hydrograph and chemograph simulation.

A second consideration for application of the NPS model in Honey Creek is that the flow pathways are different from that envisioned in the basic model structure. While modification of the algorithms would improve the simulation of moisture storage and movement, it was felt that the model should be applied in its original form and all adjustments made by the calibration process, to allow full evaluation of the model. That is, the model can be improved for this particular basin, but then its transferability to other basins will be limited.

This study is interesting in that it attempts to transfer the NPS model based on small test plot research to large watershed land management in one giant step; in retrospect, it might better have been accomplished by building up from a series of small subbasin applications, with corresponding model evolution. However, the usual constraints of time, money and data necessitated that the work proceed in its present form. The reader should carefully distinguish between problems and limitations associated with the model itself and those inherent in the Honey Creek data base, especially the rainfall data.

The NPS model is part of a set of models under development by EPA's Athens Environmental Research Laboratory. In addition to NPS, the Agricultural Runoff Management (ARM) model is a process-oriented model describing the fate of pesticides and nutrients on the land surface. The ARM hydrology module is similar to NPS. A system is currently under development which links the hydrology and pollutant generation modules from the ARM and NPS models with channel process algorithms and a data management system. This system, called the Hydrologic Simulation Program-FORTRAN (HSPF), is based on the proprietary Hydrocomp Simulation Program and is expected to be generally available in early 1979.

SECTION 2

CONCLUSIONS

The work described in this report is applied research; although the NPS model is used as the basic tool for analysis and subsequently modified for that purpose, many of the deficiencies identified in the version used for this application have since been corrected, are presently being addressed or could have been better considered under the "sister" ARM model. The important question answered in this study is what will be necessary to use models of this general type as operational tools for agricultural land management analysis. It is our conclusion that such an objective is possible within the existing model structure and framework, given certain basic data requirements and model refinements. The existence of detailed hydrologic, chemical and meteorologic data for a watershed to be calibrated cannot be assumed without understanding the limitations and requirements of the model itself. Routinely gathered stream chemistry and weather data as presently collected by the various agencies are inadequate for a model such as NPS. The investment in stream sampling and chemical analysis for the data base used in this study (1000 samples, storm and non-storm over two years, 1 station) represents a substantial cost, but it is obvious that a much greater investment would have to be made to produce a calibration that is truely satisfactory. For a basin of this size, no less than five stream stations should be used, plus at least three continuous rainfall recording stations.

One of the complimentary features of this watershed is the existence of a computerized land resource data base, which greatly facilitated the sub-basin analysis for routing (Section 9) and the spatial variability of selected land management practices (Section 10). Given certain further refinements in the basic NPS algorithms, such an integration of the land data system with a hydrologic and chemical model would be even more powerful a tool for analysis of alternatives. This line of investigation warrants further research.

Original NPS Model Deficiencies

Many of the limitations experienced with initial model calibration were recognized by the original model developers (EPA, 1977a), but it is important to describe the experience in this watershed. The "scale" problem associated with the NPS model in its original form cannot be overestimated, as the application to basins greater than 50 hectares requires more than just subroutines that estimate fluid wave movement and particulate transport through channel systems, as have been developed in this study. The model in its present form must be revised to consider the time delay of the subsurface flow component, both interflow and groundwater, beyond the adjustment allowed by the parameters IRC and KK24. Conceptually, the model simulates an infinitely small basin in which the discharge of interflow and groundwater occurs far too quickly, producing a hydrologic response that is too rapid for even the smallest of basins. The runoff response must be delayed temporally by a "time of saturation" for all land areas beyond the stream channel and wetland areas. A spatially variable UZSN might be one way to simulate this effect, based on a classification of drainage types or something similar. In addition, the "Interflow" pathway should draw from the lower zone storage, rather than the upper zone (Fig. 3, LANDS simulation,NPS Model,EPA 1977a).

For a larger watershed (∠ 50 ha), the movement of fluid wave, fluid parcels and suspended particles through the channel network and the integration of a number of sub-basins must be considered before a broad application of the NPS model is possible. This study offers some rather simplistic approaches to this set of problems and produces a satisfactory result. The key question raised in the pursuit of this solution is how important is the exact shape and timing of a hydrograph, a chemograph, or both, if the total simulated quantities are correct. The answer is fundamental to all mathematical modeling analysis: do we optimize the simulation, or try to understand the process that produced the actual data. For example, the chemograph peak preceding the hydrograph peak implies that the suspended solids come from only part of the basin; whereas the water comes from a much larger area, but with much of it delayed in movement through the soil. This is reinforced by the knowledge that in the open channel, the fluid wave will move faster than the suspended solids. The spatial differentiation of these chemical response areas is essential to management application, and so the use of this model as a decision-making tool must go beyond the "lumping" of key parameters such as soil and land cover characteristics. This applies to both the LANDS and especially the QUAL sub-routines, where exponents such as KSER are far too general.

The precedence of the hydrograph peak by the chemograph is considered by some investigatiors (Verhoff, unpub.) as evidence that the chemograph is produced almost entirely by in-channel processes and is not the direct result of land runoff during a storm event. There is little question that channel scouring and deposition processes take place during runoff, resulting in meanders, flood plains and other fluvial characteristics. It is unlikely, however, that any major portion of the pollutants carried out of the watershed originated in the channel itself. In all probability, the channel storage of fines is a temporary sink of materials, eroded from the land surface, in transit out of the basin. In either case, for the NPS model to satisfactorally deal with this question some consideration must be given to include a "channel processes" algorithm in the chemograph routing analysis, (as presently included in HSPF) a step that was not taken in this initial study.

Potency factors should be held constant for variables such as particulate phosphorus, which have a strong relationship with suspended solids. This is not to suggest that these factors do not vary slightly with different storms and seasons, but by allowing them to be varied on a monthly basis as has been done in prior work with the NPS (the result of initial focus on urban watersheds), they tend to be misleading and may mask hydrologic variability as chemical variability. Other elements of the QUAL sub-routine are too coarse, at the present, to warrant a degree of refinement such as monthly potency factors.

The evapotranspiration process, as discussed in the report, is the key to sucessful moisture accounting in a basin. A monthly value of K3 (as presently included in ARM) would not only be an improvement but also is supported by the comparison of adjusted pan evaporation data with various evapotranspiration estimates. Variable K3 values were used in this modeling study for model calibration runs of 1976 data, but not for model verification with 1977 data, although a better result could be anticipated if K3 had been varied. The potential use of Palmer Index data, available throughout the country, should also be recognized as input in the absence of pan evaporation data, or even in lieu of it.

A great deal of improvement and refinement of the QUAL algorithms is recommended, with correlation studies of JRER with rainfall kinetic energy and antecedent rainfall (implying an event or seasonally based value) and analysis of KRER with "K" (erodability) values in comparative watersheds under identical or similar hydrologic and cover conditions. The KSER exponent, as discussed in the report, simply contains too many distinct variables to be lumped together, except in instances where spatial definition is not possible. Two alternatives are possible: rewrite the equation to distinguish the variable or develop "cooccurrence" statistics on the combination of slope, soil particle size distribution, cover and drainage density in respective sub-basins from the data base (envisioned as a four-way matrix) and calibrate KSER using a sub-basin data set. In either case, the coefficient must be refined to allow any type of management analysis of the basin.

Although the preceding discussion focuses on inadequacies of the NPS model in its unmodified form, in all fairness it must be recognized that the hydrologic simulation achieved by run 33 was fairly good, except for the exaggerated peaks and time displacement. Also, the suspended solids simulated was very close to the actual mass transport, although the simulated transport came off in a flash with each storm.

NPS Model Extensions

The extensions to the basic model that were made for the Honey Creek calibration are listed here, with pertinent conclusions.

In-stream Time of Travel (TT). The time of travel for both fluid waves and particles was estimated for main channel segments and added to respective sub-basin simulated hydrographs. Kinematic velocity was used for fluid waves and fluid velocity was used for particles, both estimated from channel geometry and hydraulic equations of open channel flow.

Intra-basin Time of Concentration (Tc). Sub-basin simulated hydrographs were displaced temporally by an estimate of time required for fluid and chemical wave production, based on sub-basin size, cover and average slope.

Sub-basin routing (IBR). Simulated hydrographs for sub-basins were redistributed temporally, or routed, to approximate the time lag of actual hydrograph development, over the period of Tc (as a function of Tc).

Sub-basin integration. A routine was developed to integrate the modified and displaced hydrograph and chemograph simulations at a downstream station (Melmore).

Output. An output plotting capability to generate both simulated and actual output on a CALCOMP plotter, at variable scales, was developed and used.

Other Program Changes. A few mechanical changes were made in the program over the research study to improve output format, data processing or general usability.

The initial conclusion reached with respect to the extensions listed is that they are essential for application of the NPS model to any watershed larger than a few hectares, and a basin the size of Honey Creek (47,000 hectares) should be calibrated for sub-basins individually, rather than attempting to calibrate the entire watershed at only one station (Melmore). Given the data available for this effort, much remains to be learned in taking such a large step at once. Considering the simplicity of routing equations used and the actual complexity of fluid wave and particle movement through the basin's infinite number of pathways, the simulations produced are satisfactory. This sense of satisfaction, however, should not allow complacency with the results. The simulations mask many important but subtle processes that must be understood to improve land management techniques. The NPS model, even with the modifications made herein, is not yet able to completely simulate and distinguish all the effects of possible changes in agricultural land management (other than variations in COVVEC and other factors as discussed in Section 10) potentially suitable for this watershed.

Finally, it is concluded that the use of NPS and other hydrologic-chemical models for land management analysis will result in more accurate estimates of erosion reduction than methods such as the USLE. Continuous accounting of soil moisture is the key to predicting the magnitude of hydrologic and chemical response in a watershed, all other things being equal. There is also the very real danger of blanket application of management practices that could be as effective if applied on a very selective basis. To avoid this, such models must be sensitive to spatial variability.

SECTION 3

RECOMMENDATIONS

The following recommendations are intended to accomplish two purposes: improve the NPS model in general terms to make it more applicable as a management tool and evaluate the potential role of modeling in improving agricultural land management in a demonstration watershed. On one hand, many technical steps can be taken to improve this particular model, representing state-of-the-art technology for analyzing the problem of diffuse pollutants. One needs to evaluate the overall benefits of developing a "better" model, however, to determine whether the additional investments are warranted.

ROUTING SUB-ROUTINE

A real question exists as to how much more refinement need be added to the procedure developed in this study for management analysis. Better routing routines can certainly be written given the intrabasin hydrographs and chemographs for calibration. With actual sub-basin chemographs and hydrographs, the routing coefficients and hydraulic storage can be estimated, with incremental hydrograph and chemograph routing. This result could then be compared with the more simplistic approach, using the same data sets.

MODEL REFINEMENT

Even with the addition of routing sub-routines, the NPS model should be refined in several important ways.

Spatial Differentiation

For the application of this model to land management analysis, it will be necessary to distinguish among those elements or combinations of factors within a hydrologic unit or sub-basin that will vary both hydrologic response and/or pollutant generation. This is not to suggest that the responses are mutally exclusive, but rather that a given land area may allow a major portion of incident precipitation to contribute to runoff without contributing significant pollutants. Certainly it would be impractical to analyze each unit area, or cell, within a basin individually, but the aggregation of cells into clusters or response groupings within hydrologic units would be entirely feasible, given the type of data base that exists in Honey Creek. From a modeling point of view this step would not add greatly to the model's complexity, but should greatly improve its ability to predict the highly variable response to storms that are a function of soil moisture storage. More importantly, the evaluation of various land management techniques, which are almost entirely dependent on spatial variables within a sub-basin (soils, cover, slope), could be based on the simulated hydrologic and chemical responses.

The initial analysis of "hydrochemical response" groups could be done within the existing LRIS framework, applied to the present NPS algorithms, and evaluated. With calibration, the selected management practices could be evaluated for application and suitability in a given hydrochemical response group and the respective algorithm modified, if necessary. It is suggested, however, that the basic structure of the existing NPS model be left intact until it is shown necessary for the sake of evaluating sensitivity to a given practice.

QUAL Algorithms

As discussed previously, several of the equations and parameters used in the QUAL sub-routine require refinement. The KSER parameter includes too many real variables to allow any kind of calibration to the real world, and its refinement should be a separate task in itself. The apparent sensitivity of this parameter to land surface conditions makes it an important management variable, but lumping this factor together with fixed watershed variables such as sediment particle size and slope only makes the comparison of practices more difficult. Drainage or grading modifications, such as terracing or berms, that attempt to alter the overland flow pathway will also be impossible to distinguish. The wide range of values experienced in various calibration efforts reflects the uncertainty in the use of this parameter in its present form. The exponent JSER is held to a very limited range of variability. The reformulation of this equation could significantly improve the applicability of the NPS model for management analysis.

The foundation for development of the detachment co-efficient (KRER) and exponent (JRER) is much more firmly based on prior research. It is recommended however, that their exact relationship with rainfall kinetic energy (E) or erodability (R) be better defined, as well as the relationship between KSER and the "K" factor of the USLE. A wealth of experimental data exist with respect to the first problem, whereas the second may be solved by analysis of multiple sub-basins with all variables held constant except soil type. Certain storm events in the Watkinsville data set might meet the criteria, or analysis of much larger sub-basins such as in Honey Creek or the full Sandusky. Refinement of these two relationships will allow most of the calibration process to take place in the transport algorithm.

Cover Factor (COVVEC)

The most obvious variable controlling sediment production in a watershed is the vegetative land cover; the most straightforward management practice is to modify the density and timing of this cover on cultivated fields. Given these two facts, it would seem obvious that the COVVEC variable would be the most important basin characteristic to be measured prior to application of the NPS model. Ground cover in an agricultural watershed such as Honey Creek, however, varies both temporally and spatially in a given year, and from one year to the next. Data collecting efforts for COVVEC during 1976 in Honey Creek - consisting of photointerpretation and computer coding of IR imagery and farmer surveys - were exhaustive for a basin of its size, allowing the NPS model to be finely tuned for this parameter. With the passage of time, the quality of this factor in the data file will deteriorate without some simplified method of updating. Prior research with NASA in this basin has suggested that low altitude multispectral scanner (MSS) data collection is prohibitive in cost and of limited value, as is high altitude photography. The question then is whether a cheaper, lower resolution imagery source such as LANDSAT can serve this purpose. A large NPS calibrated basin such as Honey Creek should be analyzed using a series of available LANDSAT tapes to determine whether bare soil, live vegetation, dead vegetation, snow and combinations of these can be distinguished at critical times of the year. Again, this is a study subject in itself, but its potential importance for widespread acceptance of the NPS model should not be overlooked.

In spite of the various deficiencies experienced and identified in the NPS model, or perhaps because of them, the research summarized in the preceding paragraphs must be conducted. Model development is an evolutionary process, with each succeeding generation or product more useful, if the underlying structure and theory are sound. In this respect, the NPS model offers the greatest potential of presently developed tools because of its focus on continuously accounting for soil moisture, the key determinant in both hydrologic and chemical response in a watershed. Only by knowing what the antecedent moisture conditions are in a watershed with respect to precipitation events can we hope to understand and intervene in the process of agricultural erosion. Any analytical approach that neglects this consideration, no matter how finely divided the data set that describes the spatial determinants of the watershed, will prove inadequate. At the same time, the combining of sensitive parameters for a watershed as is presently done in NPS parameters such as KSER will not give sufficient definition for management analysis. The most useful model must be structured with the strong features of both approaches; continuous moisture accounting with spatial differentiation of variables.

Research Issues

Several fundamental research questions having tremendous implications for the success of land management techniques to reduce soil associated pollutants are only partially answered for diffuse sources. First and foremost is the question of source areas: classic soil erosion theory as well as test plot data tells us that, all other things being equal, the more steeply sloped areas, usually in the headwaters of a basin, will contribute more erosion. On the other hand, partial area hydrologic theory (Dunne, 1976) suggests that overland flow occurs on only a limited portion of the basin: those low lying,high water table soils contiguous to the stream channel. Alternative conclusions will lead to very different management strategies. If most of the sediment being carried from an agricultural watershed is coming from only 15 to 20% of the basin land area, and that area is the less permeable, poorly drained soil, the improved drainage and/or reduced cultivation technique might be more successful than those strategies which attempt to minimize rainfall erosive energy by improving cover conditions, or reducing velocity of overland flow by slope reduction.

The sediment transport question is also important. Does material take many years to move out of a watershed, with subsequent scouring and deposition in a number of temporary sinks, such as swales, ditches and stream bottoms, or does the majority of material observed in passage from a basin during a storm event originate on the land surface during that storm? This question also weighs heavily on the selection of suitable land management techniques. The time required to measure any success achieved by such alternatives as fertilizer reduction is very much dependent on the answer to this question.

It is recommended that in our pursuit of a better model to simulate the mechanisms of diffuse pollutant production and transport that we not ignore these basic research issues. The improvements in water quality necessary over the next decade must be at the lowest possible cost, necessitating a better understanding of the processes involved than we presently possess.

SECTION 4

BACKGROUND

In order to understand the logic behind parameter selection and modifications to existing model algorithms, it is necessary to understand the unique characteristics of the Honey Creek basin and both the potential and limitations of existing hydrologic and chemical records.

PHYSIOGRAPHIC SETTING

The Honey Creek basin (D.A. 179 sq. mi.) is a tributary to the Sandusky River (D.A. 1430 sq. mi), which drains from north central Ohio into the western edge of the central basin of Lake Erie (GLBC, 1975). The surface physiography of Honey Creek is characterized by glacial deposition: 57% of the land form is ground moraine, 21% is end moraine and the balance is comprised of lacustrine deposition, outwash, flood plain and glacial drift. Basins closer to the lake shore lying to the west of the study basin (Honey Creek is 30 miles from Lake Erie) are comprised predominantly of lacustrine materials and are even flatter; the Portage is a good example. Within Honey Creek, the land is characterized as being poorly drained with a portion of the headwater area comprised of a swampy wetland, the remains of glacial Lake Willard. A major geologic feature of the regional subsurface strata is the axis of the Cincinnati Arch, a "slightly north-plunging regional anticline whose long axis extends from north to south across western Ohio from Cincinnati to the vicinity of Toledo." Running generally parallel and to the west of the Sandusky River, this feature defines the sedimentary beds that comprise a carbonate aquifer that many geologists believe constitutes the major ground water flow system (Norris, 1974). The recharge area for much of this aquifer is in the headwaters of the Scioto River basin, lying south of the Lake Erie basin divide. (Fig. 1). This movement of ground water north toward the Lake shore is an important factor in the Honey Creek basin, controlling the high water table conditions that exist in most of the watershed.

The surface and sub-surface conditions in the Honey Creek basin suggest that little, if any, surface water moves into deep or inactive groundwater storage. In fact, even the active groundwater storage may be minimal because the base flow values average 0.01 cfs/sq.mi. and less. The watershed is extensively

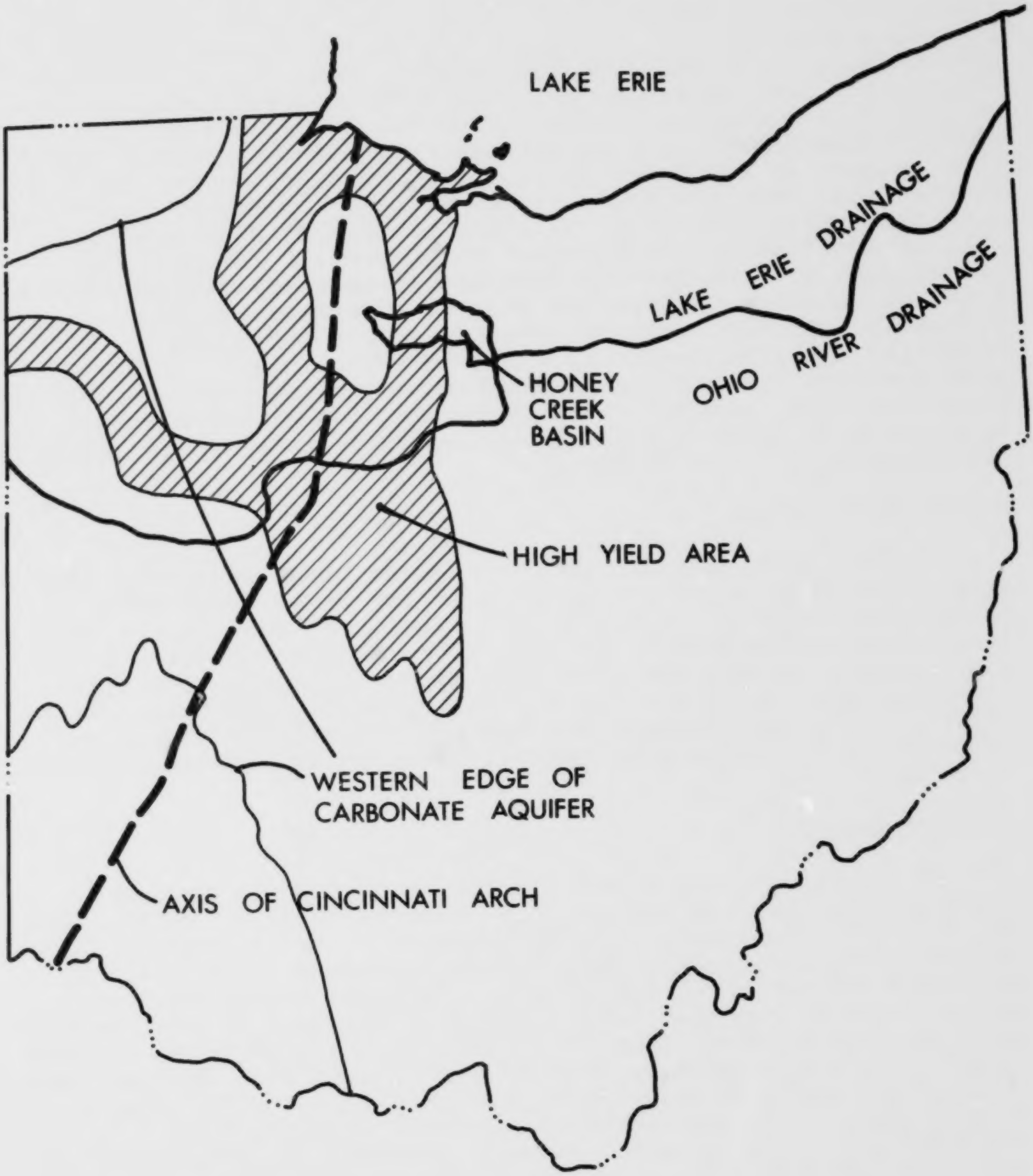
LAKE ERIE
LAKE ERIE DRAINAGE
OHIO RIVER DRAINAGE
HONEY CREEK BASIN
HIGH YIELD AREA
WESTERN EDGE OF CARBONATE AQUIFER
AXIS OF CINCINNATI ARCH

Figure 1. Hydrogeology of Honey Creek basin.

underdrained with artifical tile, a necessary feature for cultivation usage. The majority of drain tiles lie at a depth of 3 to 5 feet below surface, forming a subsurface drainage network not unlike a first order stream network. The flow of water through the soil mantle to the tile, the gradient, size and age of tile, the elevation of the outlet and possible submergence during storm runoff all contribute to the interaction of this flow pathway in the basin hydrograph. For the initial NPS model calibration, the tile drain system will be conceptualized as very rapid interflow (Fig. 3, LANDS simulation NPS), but this will be modified in future model development. The existing hydrographs for the Melmore gage do not show any distinct inflection point on the semilog plot of recession curves, suggesting the separation of true surface runoff. This interflow and groundwater flow may be impossible to calculate accurately on the basis of hydrographic analysis alone. The chemistry data, however, used in conjunction with the recession curve do offer insight as to the tile drain flow; this is discussed in a later section.

STREAM FLOW RECORD

The U.S.G.S. established a permanent stage recording station at Melmore (D.A. 149 sq. mi.) in the Honey Creek basin in January 1976 to record hourly stage readings. A rating curve, with adjustments, has been in development until the present. Other flow measurements in the basin have been irregular and are inadequate for the present model calibration effort. Thus the Melmore data set will constitute the primary information for model development, based on a 21 month record. (Fig. 2).

WEATHER RECORD

No continuous precipitation record exists within Honey Creek proper, but two observation stations exist at Tiffin (Fig. 3), just at the mouth of the basin. One record is hourly values, non-recording, and the other is a daily record. The basin is bracketed by two other daily record stations at Plymouth and Bucyrus, which are equidistant from the centroid of the basin with the Tiffin gage, (each ≈ 14 miles). The elevation of both these stations is several hundred feet higher than Tiffin. Review of major storm events over the period of record shows a fairly good consistency between these three stations, with the exception of brief summer thunderstorms, which for the most part, produce little runoff at the Melmore gage. The snowfall and snow-on-ground record is also from Tiffin, whereas soil temperature is taken from the Ohio Agricultural Research Center at Wooster, approximately 55 miles east southeast of Honey Creek. Although not ideal, the available weather data appear adequate for initial calibration. Of course, the time factor is significant, and the hydrographs will be evaluated

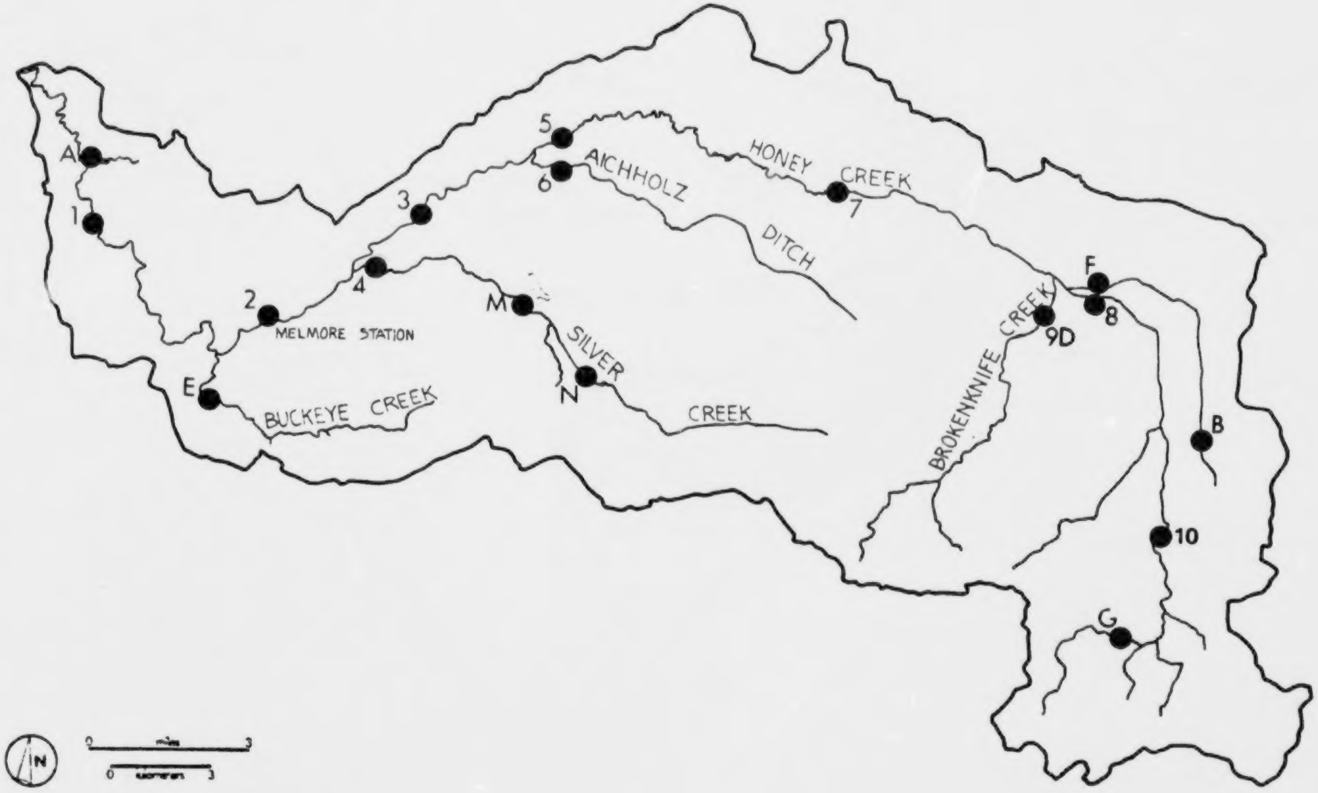
A
1
2
MELMORE STATION
3
4
5
6
AICHHOLZ
DITCH
HONEY
CREEK
7
E
BUCKEYE CREEK
M
N
SILVER
CREEK
BROKENKNIFE
CREEK
9D
F
8
B
10
G
N
0
3
0
3

Figure 2. Honey Creek basin sampling stations.

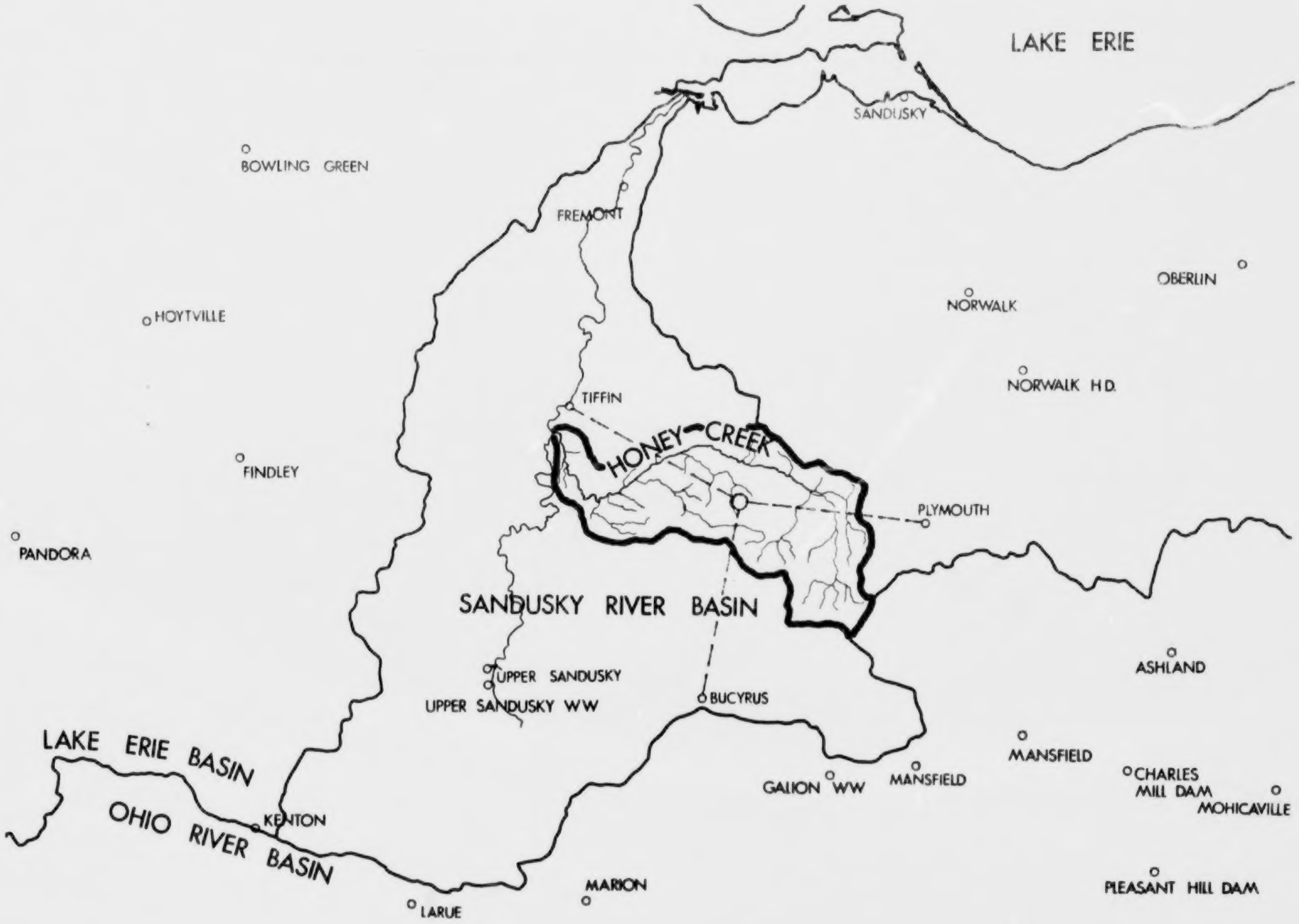
LAKE ERIE
SANDUSKY
BOWLING GREEN
FREMONT
OBERLIN
NORWALK
HOYTVILLE
NORWALK HD.
TIFFIN
HONEY CREEK
FINDLEY
PLYMOUTH
PANDORA
SANDUSKY RIVER BASIN
ASHLAND
UPPER SANDUSKY
UPPER SANDUSKY WW
BUCYRUS
LAKE ERIE BASIN
MANSFIELD
CHARLES MILL DAM
GALION WW
MANSFIELD
MOHICAVILLE
KENTON
OHIO RIVER BASIN
MARION
PLEASANT HILL DAM
LARUE

Figure 3. Climatological stations.

primarily by shape rather than time, because a time displacement could easily be expected.

CHEMICAL RECORD

The Melmore data set consists of 967 samples through July 10, 1977, with measured parameters as shown in Table 1. For model calibration, the parameter " Particulate Phosphorus" (TP_{part}), defined as TP-OP, will be used in comparison with suspended solids. This relationship is excellent for the data set and gives a " potency factor" of 0.002,(Fig. 4). Neither the OP nor the NO_3 records lend themselves to so simplistic an analysis, however, and the flow and seasonality influences are predominant. Thus the initial calibration of the QUAL subroutine will use the SS and TP_{part} parameters only.

Table 1.

WATER QUALITY RECORD SUMMARY

HONEY CREEK BASIN

Melmore Gage :	1969-1975	Irregular grab sampling Ortho Phosphate (OP) Total Phosphate (TP) Suspended Solids (SS)
	1976-77	Daily plus 6 hr. intervals During runoff OP, TP, SS, NO_2+NO_3, NH_3 Bi-weekly - pH, Cl, Si, TKN Irregularly-conductivity
Secondary Stations from 8-6-76 to present		Grab sampling over runoff plus weekly. (Same parameters as Melmore)

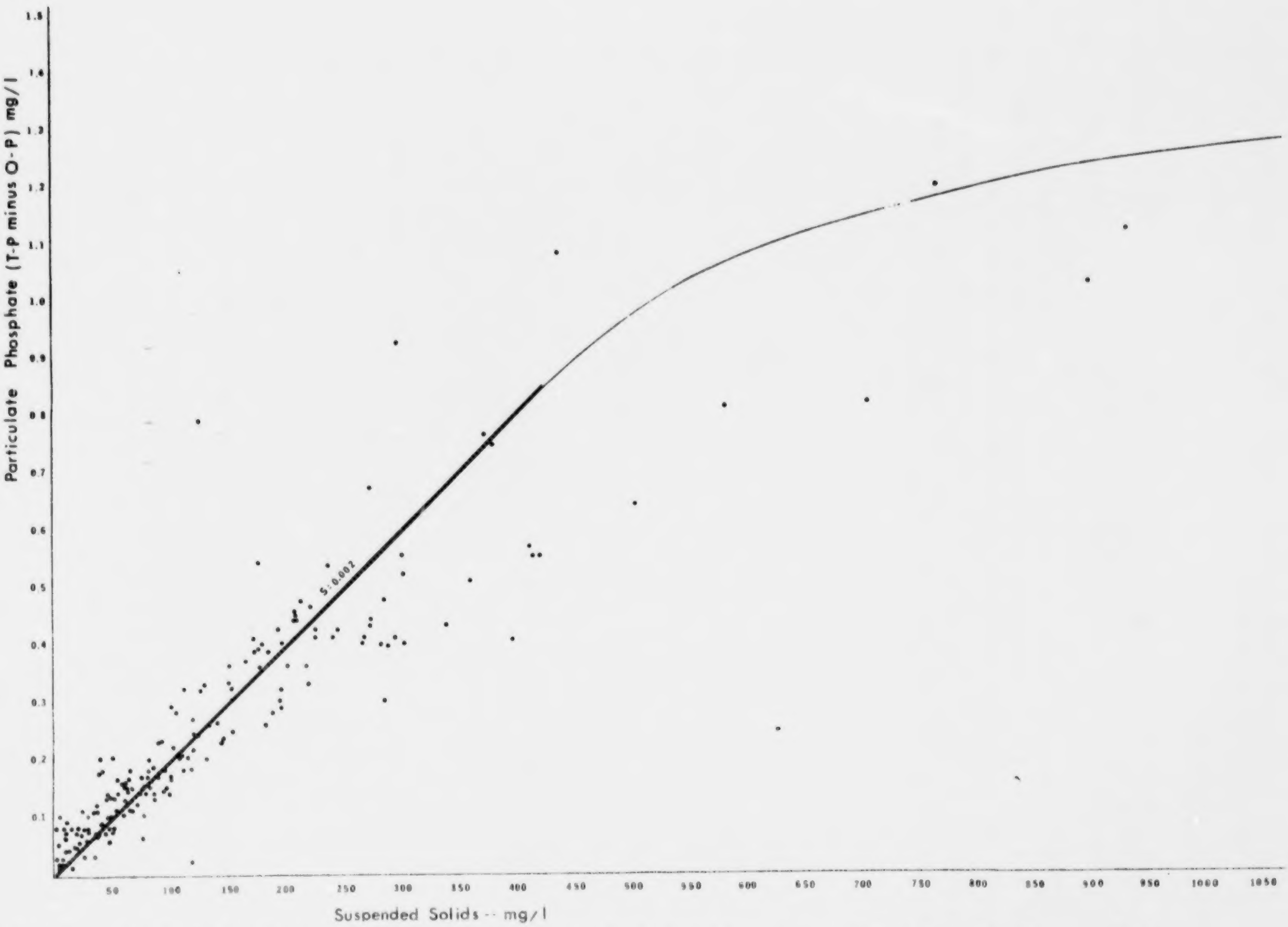

Figure 4. Particulate Phosphorus- Suspended Solids curve,Melmore station, 1976.

SECTION 5

BASIN CONSIDERATIONS

SURFACE AND SUB-SURFACE FLOW SYSTEM

The conditions that exist in the Honey Creek basin with respect to water movement through the soil mantle are very different from that conceptualized in the general development of the NPS model. For this reason, simulation of the flow pathways will require the development of different algorithms for certain portions of the model. First, the Honey Creek flow network will be compared diagramatically with that envisioned in the NPS model; next, each model parameter will be reviewed and modified, where necessary.

Figure 5 shows a simpified diagram of the flow pathway envisioned in the NPS model, with the movement of interflow along the saturated zone above the water table dependent upon the soil permeability and hydraulic gradient, just as active groundwater storage will contribute to streamflow as stream level recedes. In Honey Creek, much of the cultivated land has been extensively artifically drained with tile networks (of varying dimension, design and condition), producing a system as simplified in Figure 6. The tile system provides a flow pathway which can be thought of as first order stream input, very rapid interflow or a short term reservoir of soil moisture, because in many soils the intervening soil layers have low permeability and the time of movement throughout the lower zone by inflitration and perculation may be significant. Upon reaching the tile system the movement can be very rapid if there are not hydraulic restrictions to flow (i.e., flooding of outlets). The zone between tiles (Fig. 6) will comprise the active groundwater storage zone, varying in capacity as infiltration drains into the tile and eventually decreasing to zero as the water table returns to the invert elevation of the tile network. The secondary active groundwater storage zone situated below the tile system and comprising long term base flow is quite small, as reflected by the annual hydrograph for 1976 (Fig. 7) which shows base flows decreasing close to zero for the full basin. In effect, the introduction of an artifical drainage network under much of the basin has lowered the water table sufficiently so that the basin is almost totally dependent on precipitation input for maintenance of stream flow. This pattern is characteristic of most of the region in northwestern Ohio and southeast-

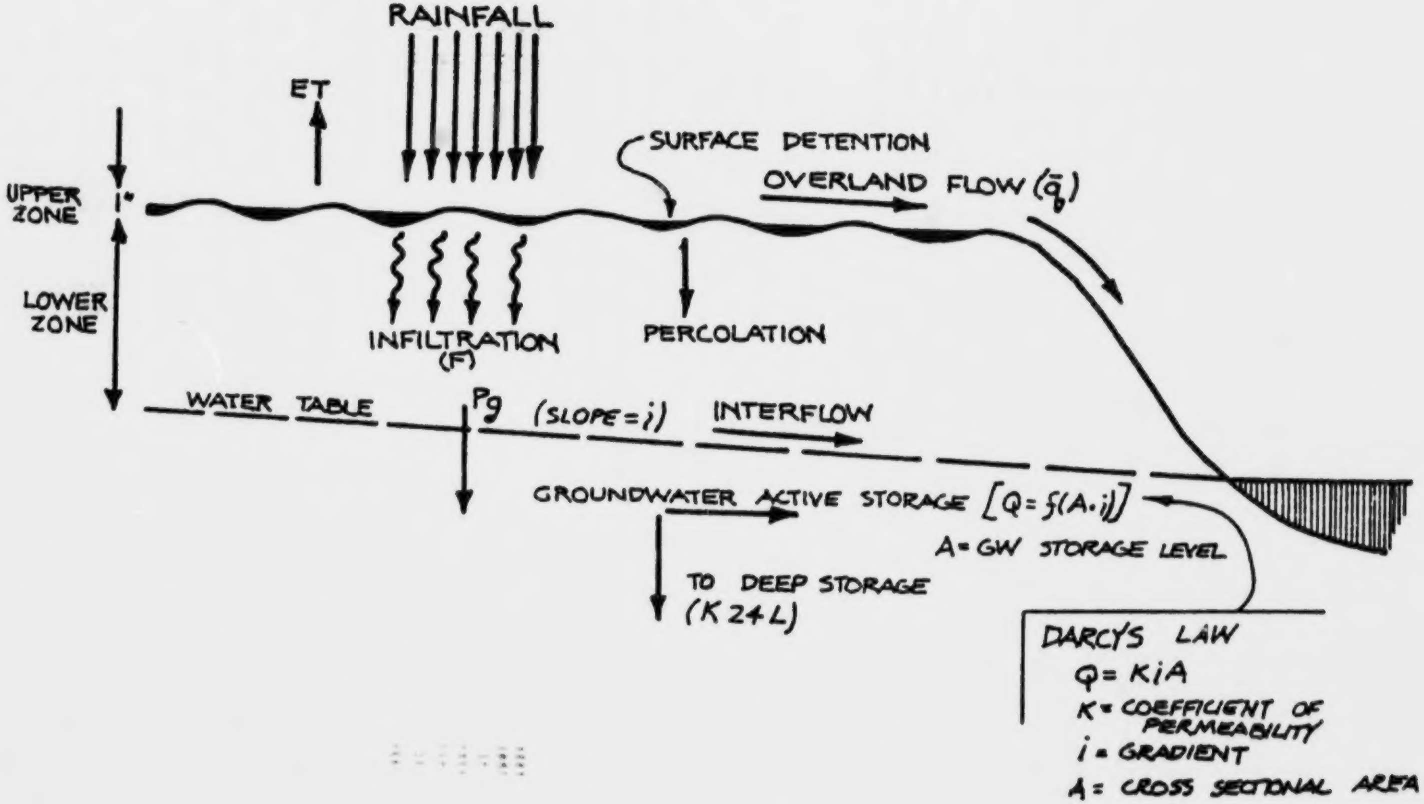
RAINFALL
ET
UPPER ZONE
LOWER ZONE
i*
SURFACE DETENTION
OVERLAND FLOW ($\bar{q}_0$)
INFILTRATION (F)
PERCOLATION
WATER TABLE
Pg
(SLOPE = i)
INTERFLOW
GROUNDWATER ACTIVE STORAGE [Q = f(A·i)]
A = GW STORAGE LEVEL
TO DEEP STORAGE (K24L)
DARCY'S LAW
Q = KiA
K = COEFFICIENT OF PERMEABILITY
i = GRADIENT
A = CROSS SECTIONAL AREA

Figure 5. Flow pathways for NPS model.

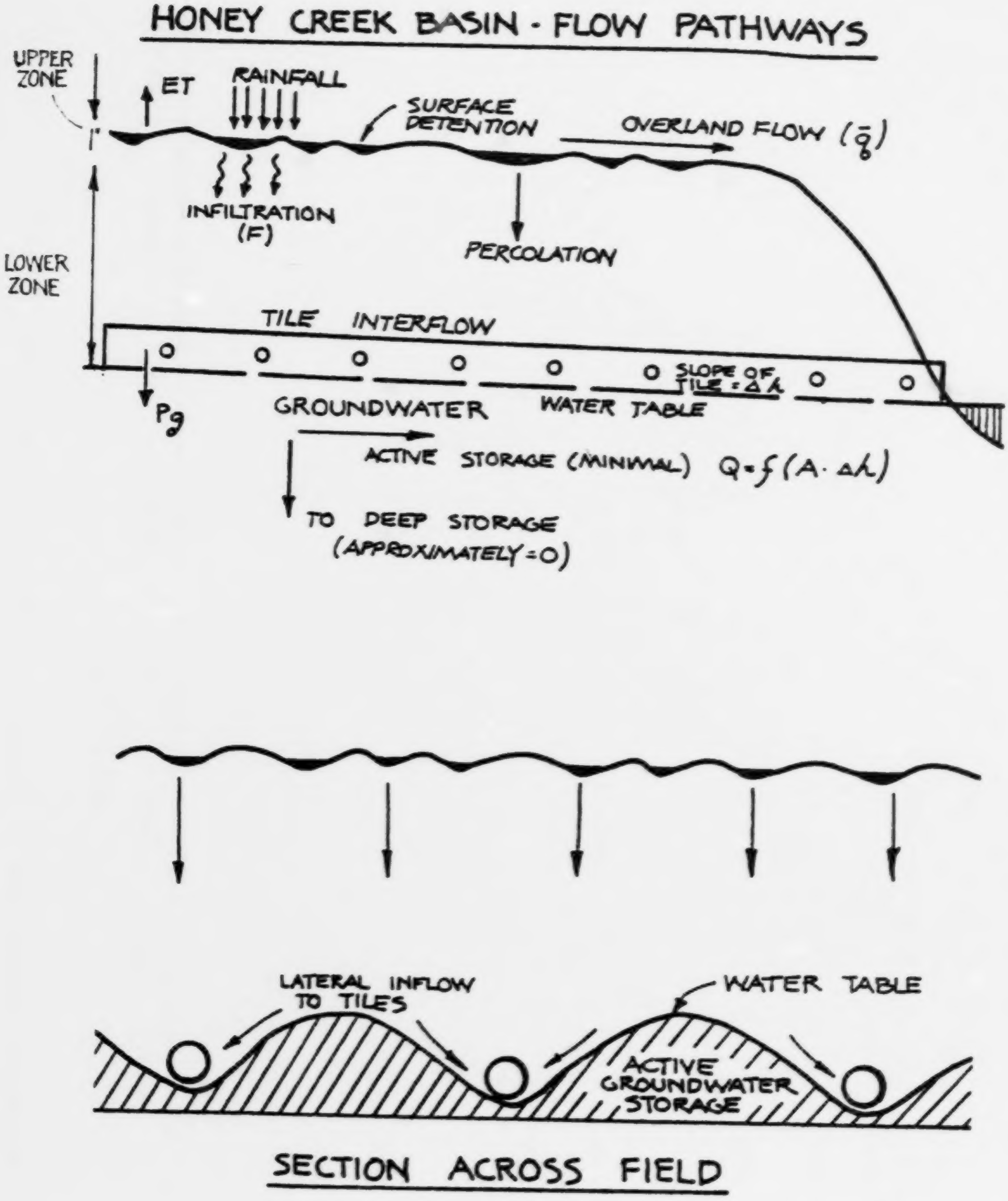
HONEY CREEK BASIN - FLOW PATHWAYS
UPPER ZONE
ET
RAINFALL
SURFACE DETENTION
OVERLAND FLOW ($\bar{q}$)
INFILTRATION (F)
PERCOLATION
LOWER ZONE
TILE INTERFLOW
SLOPE OF TILE = Δh
P_g
GROUNDWATER
WATER TABLE
ACTIVE STORAGE (MINIMAL) $Q = f(A \cdot \Delta h)$
TO DEEP STORAGE (APPROXIMATELY = 0)
LATERAL INFLOW TO TILES
WATER TABLE
ACTIVE GROUNDWATER STORAGE
SECTION ACROSS FIELD

Figure 6. Flow pathways for Honey Creek basin.

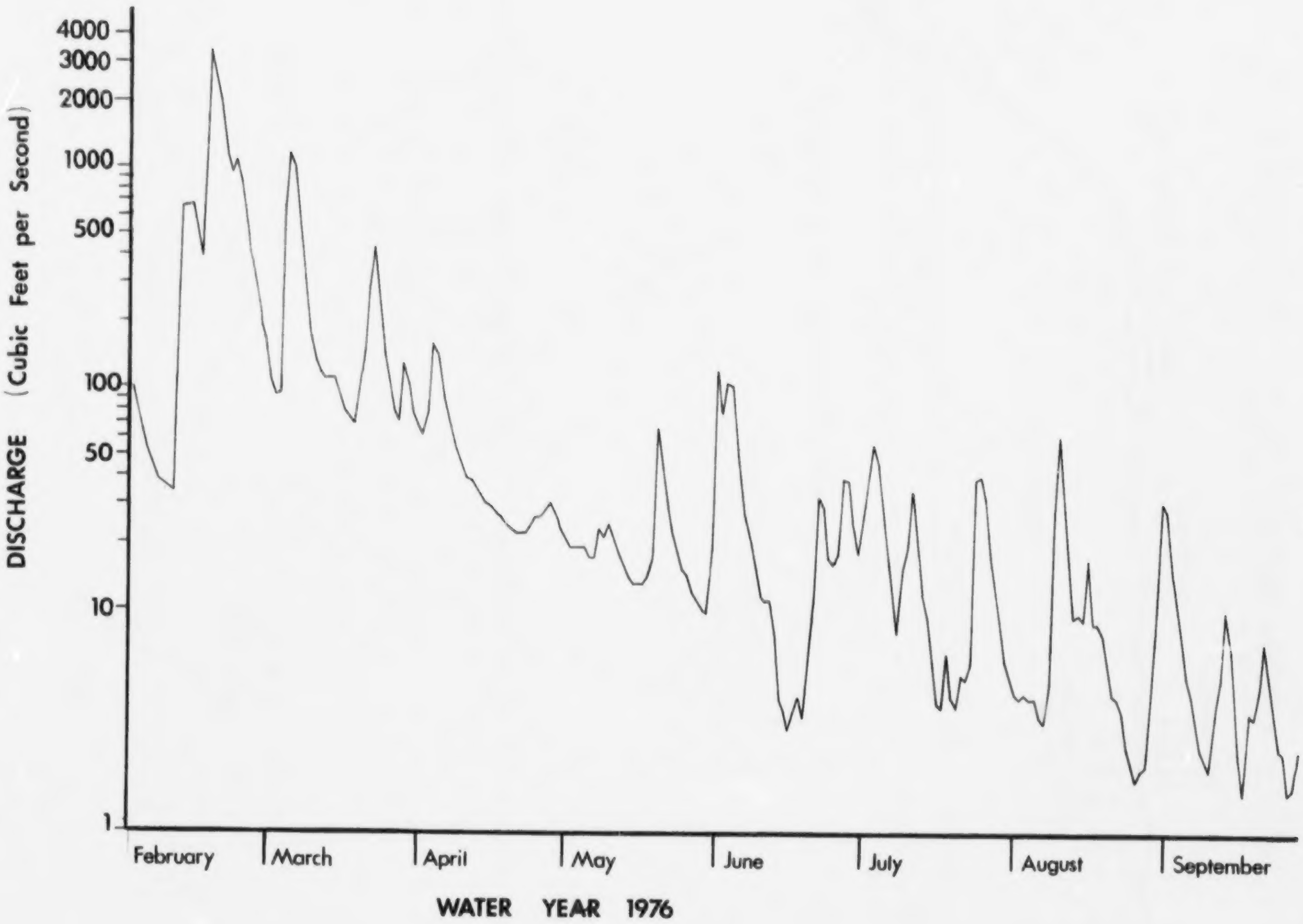

Figure 7. Daily flow of Honey Creek at Melmore station, 1976.

ern Michigan, as well as other parts of the country where tile systems are an integral part of intensive cultivation systems.

LAND RESOURCE DATA BASE

A computerized data base has been developed for the Honey Creek Basin. The data base contains spatially referenced information for those characteristics listed in Table 2. The data are encoded for a randomly located point in each of 11,700 four-hectare (approx. 9.88 acres) cells. The application of this method (Bliss et al., 1974) has proven very successful for the characterization of spatial features in land-water systems analysis, providing a statistically reliable set of information on the combination of ingredients that exist in a watershed. Figure 8 shows the location of points and cells, as encoded, in a portion of the Honey Creek basin near Attica, superimposed on a 1:24,000 quad sheet base. For each point, some 11,500 covering the basin, the data listed in Table 2 are stored in a file, which varies in size and complexity depending on the parameter. The soil file, for example, is taken directly from the SCS-5 data and includes complete information on the physical and chemical properties of each soil horizon, or layer. Other files, such as land cover, consist of a coding number for a particular coding scheme. Appendix A provides a more detailed description of the Land Resource Information System (LRIS) as it exists in the Honey Creek basin.

Of particular interest in this research study is the question as to how such a spatial data base can be integrated with a non-point source model such as NPS. The initial problem to be considered is that of estimating the type and spatial distribution of alternative flow pathways, as described in the preceding section, with the existence of tile drainage systems in much of the cropland. As shown in Table 3, the land use distribution in the basin above the Melmore gage (Fig. 2) is predominently agricultural, (82%) with the proportion of row crop to field crop about 1.7 to 1, as of June 1976. What the computer file does not contain, at present, is information concerning which cropland is presently artifically drained.

USE OF IMAGERY

Several pieces of information have been considered in order to evaluate the question of tile systems. Most townships in Honey Creek keep records of ditch construction and maintenance, many of which show up on the U.S.G.S. quad maps, but some on which are not clearly defined. Township maps show all major ditches, but do not show sub-surface tile systems. In Venice Township (Fig. 9), a survey of farms was conducted during the summer of 1976, with about a 25% sampling. One of the pieces of information gathered was the location, if known, of tile drains in the fields under cultivation by the farmer interview-

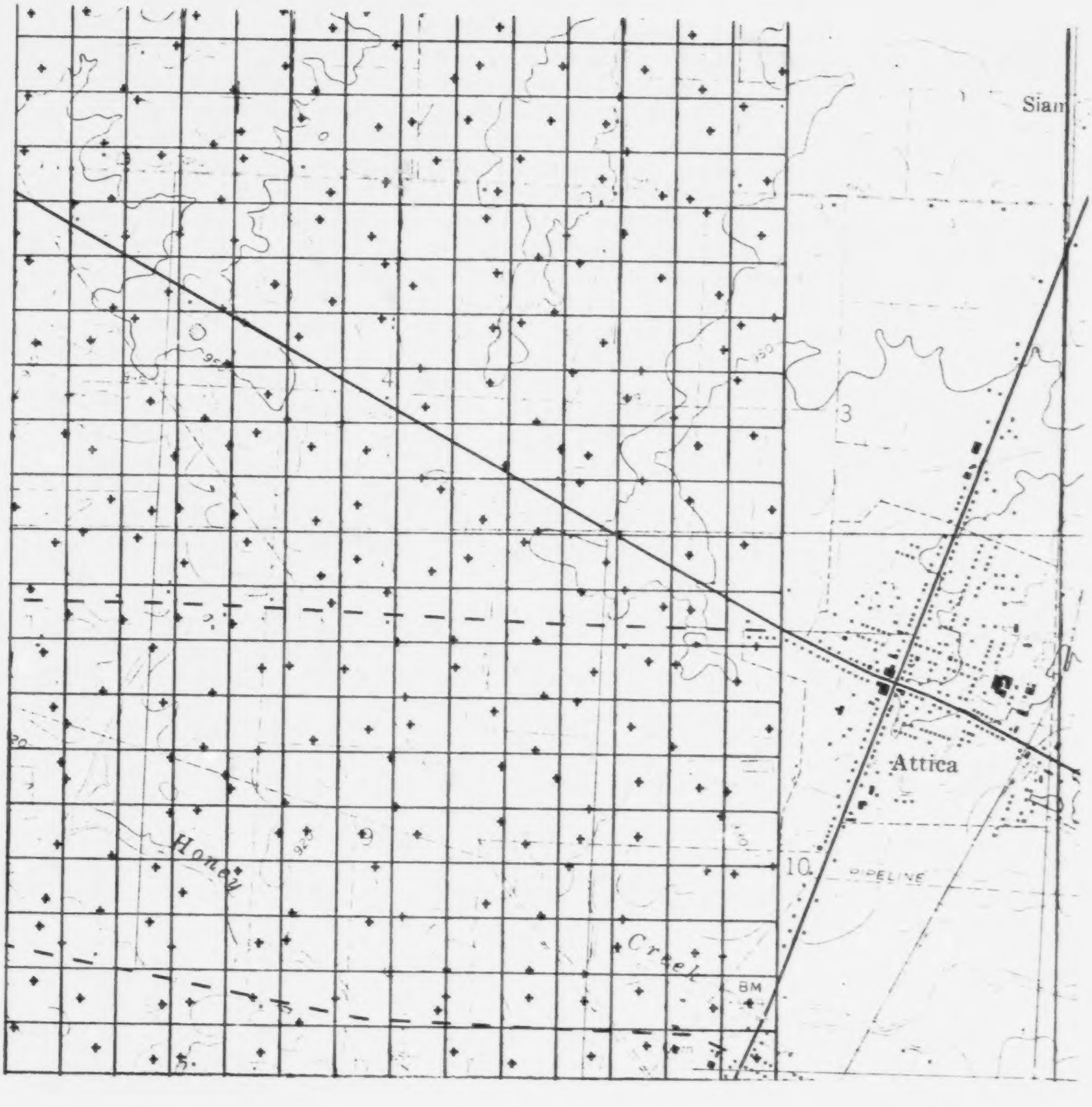
Siam
3
4
Attica
Honey
Creek
9
10
PIPELINE
BM
950
920

Figure 8. Example of cell- point data coding system, Honey Creek basin.

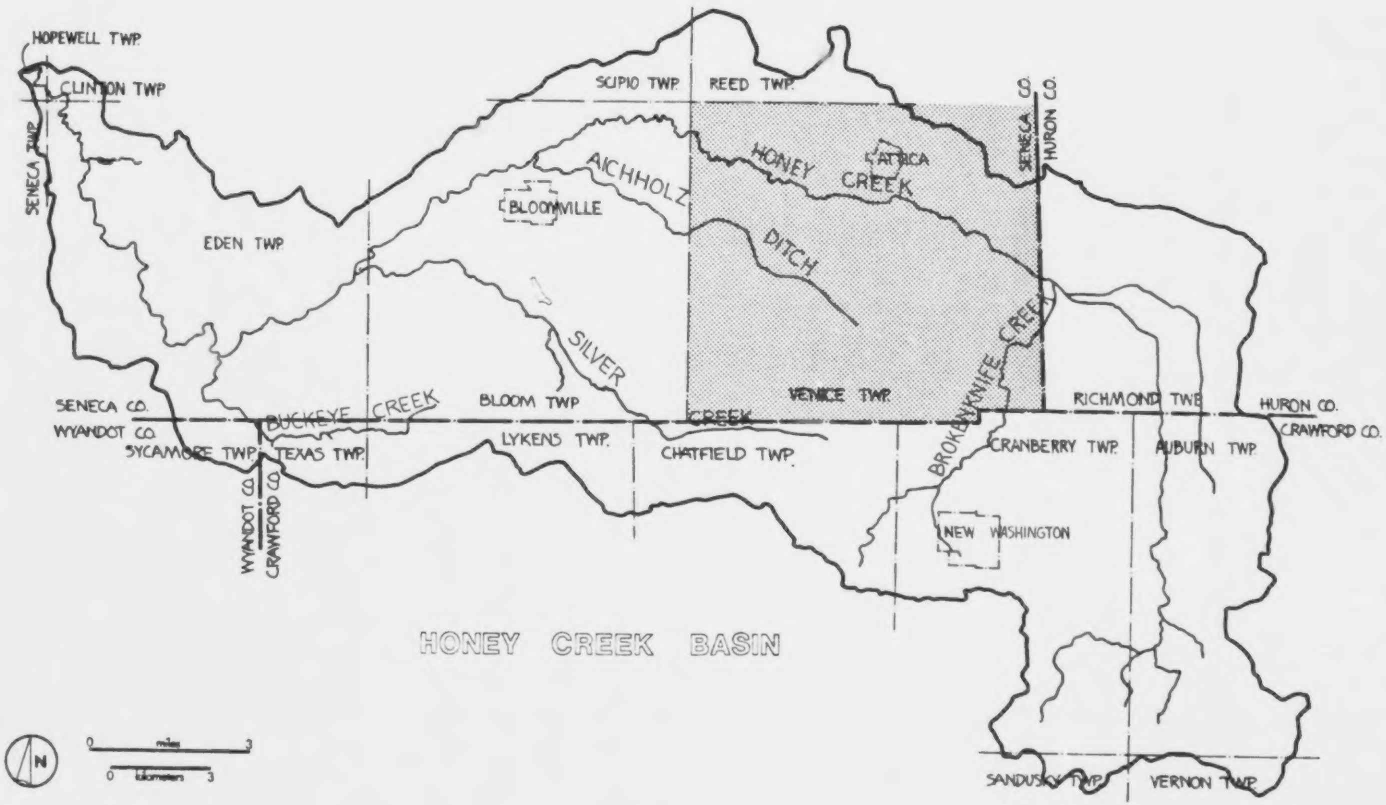
HOPEWELL TWP.
CLINTON TWP.
SENECA TWP.
EDEN TWP.
SCIPIO TWP.
REED TWP.
AICHHOLZ
BLOOMVILLE
HONEY CREEK
ATTICA
DITCH
SENECA CO.
HURON CO.
SILVER CREEK
BUCKEYE CREEK
BLOOM TWP.
VENICE TWP.
BROKENKNIFE CREEK
RICHMOND TWP.
HURON CO.
CRAWFORD CO.
SENECA CO.
WYANDOT CO.
SYCAMORE TWP.
TEXAS TWP.
WYANDOT CO.
CRAWFORD CO.
LYKENS TWP.
CHATFIELD TWP.
CRANBERRY TWP.
AUBURN TWP.
NEW WASHINGTON
HONEY CREEK BASIN
N
0 miles 3
0 kilometers 3
SANDUSKY TWP.
VERNON TWP.

Figure 9. Political subdivisions in Honey Creek showing Venice Twp.

Table 2. LAND RESOURCE INFORMATION SYSTEM

DATA FILES

For each of the 11,500 point/cells (4 ha) covering the Honey Creek watershed in a UTM grid, the following information is coded:

Land Use by both point and cell : 8 major and 37 minor classes. Dominant land use in cell and specific land use at random point in cell.

Soil Phase by soil series and slope category. Soil file data from SCS computer file for "A" horizon with suitability classes, "K" factors, "T" factors and other parameters.

Watershed in 26 sub-areas.

Slope Magnitude in tenths of a percent.

Slope Direction by azimuth from 0° to 360°.

Elevation of point in tenths of foot.

Physiographic Region by soil series groupings.

Political Sub-Division

ed. These were mapped, where possible. Finally, color infrared imagery gathered in June 1976 was studied to determine possible surface moisture patterns as an indication of sub-surface tile systems. The imagery revealed the patterns of tile systems identified in the survey quite accurately. Black and white photographs from August 1970 were also studied, but they revealed that the change in surface soil moisture offered only a mottled appearance in tiled areas, with the vegetation obscuring many drainage features. Thus it was concluded that a combination of IR imagery, photointerpretation and field survey can produce a fairly good picture of the spatial extent of tile systems. This, of course, is a level of detail that would be difficult to replicate in most modelling studies. Therefore, it was decided that for this initial model calibration effort, the spatial variation in sub-surface drainage would not be considered.

Table 3. LAND USE IN HONEY CREEK ABOVE MELMORE

Land Use Catagory	Area(ha.)	Percent of Basin
Row crop	19,820	50.5
Field crop	11,992	30.5
Other agriculture	240	0.6
Woodlot	4096	10.5
Wetlands	840	2.2
Water	392	1.0
Urban	1848	4.7
Missing Data	0	
TOTAL	39,228	

SECTION 6

MODEL CONSIDERATIONS

COVER FACTOR (COVER)

The QUAL subroutine of the NPS model requires specification of land cover values by month. These values represent the percentage of the soil surface covered by crop or crop residue that act to absorp the energy of raindrops. In agricultural regions, the simplest case is the cultivation of a single crop year after year using the same plowing, planting and harvesting schedule. In the Honey Creek watershed, several crops are grown, each with its own cover characteristics. Furthermore, certain crop rotation sequences are used so that the description of cover conditions of soy beans preceded by wheat, for example, differs from soy beans preceded by corn. Finally, two distinct land preparation schedules are used in the watershed: fall plowing, in which the soil is bare all winter, and spring plowing, in which residue from the prior crop remains on the field over the winter and early spring months.

Studies performed by RMA for the Corps of Engineers (RMA,1976) provided data useful in the development of monthly cover values. From a survey of 28 farmers in Venice Township in August and September 1976, it was learned that corn, soybeans, wheat and oats account for nearly all of the crops grown in the area. The percentages of crop land in the survey devoted to each of these four crops are similar to percentages for the three principal counties in which the Honey Creek watershed is found (see Table 4). The crop rotation sequences used by the farmers surveyed is shown in Table 5. Counting two-crop sequences in this table reveals the frequency by which each of the major crops is preceded or is followed by the other crops. These frequencies are shown in Table 6. For example, when corn is planted, 58% of the time it is preceded by wheat, 24% by corn, and 16% by soybeans. Explicit use of this information will be made below in developing the aggregate cover conditions for row crops and small grains.

Each crop was examined month by month for the cover it provides to the soil (See Table 7). The numerical assignments made are based on discussions with Seneca County SCS and SWCD personnel and on descriptions of farm management practices found in Ohio CES literature, particularly Bulletin 594 (Ohio Erosion Control and Sediment Pollution Control Guide). Row crops (corn and soybeans) are described for both fall plowing and spring plowing schedules. About half of the land covered by the Survey is spring plowed with the prior crop residue left on the field as an erosion control practice. Typical corn yields of approximately 125 BU/acre produce about 7000 lbs of residue per acre or 80% cover. In spring plowed schedules, this 80% residue cover was assumed to persist until February or March when slight decreases occur because of decomposition, wash off and blow off of the crop residues. Soybeans typically produce about 2000 lbs residue/acre which can cover about 40% of the soil surface. Wheat and oats produce 5000 and 10,000 lbs of residue per acre, respectively. In both cases, it is assumed that this residue is left on the field giving an 80% cover.

Wheat is planted in the early fall, grows slightly before winter dormancy, then reemerges in early spring. After harvest in July, wheat is followed by a cover crop - clover, alfalfa or other legume. This crop is often planted before wheat harvest and can quickly establish a good cover before its growth is slowed by winter temperatures.

Oats are planted in the early spring and harvested in July. Oats are nearly always followed by wheat.

Based on the above considerations and assumptions the monthly cover assignments were made for each crop as shown in Table 7 .

Next, each major crop was listed with the prior crop and post-harvest events. Whenever several alternatives exist, the fraction of the time each alternative occurs is designated based on information in Table 6 . This crop event list is shown in Table 8 .

Finally, a synthesis of the percent cover information (Table 7) and the crop frequency information (Table 6) was achieved by straightforward weighing of percent cover information, as shown in Tables 9 and 10 . Monthly values for row crops and for small grains are listed separately because the Honey Creek land use file spatially distinguishes these two crop categories. The weighted average monthly cover values for row crops (corn and soybeans) and small grains (wheat and oats) are summarized in Table 11 . Figure 10 shows a plot of the final percent cover values for row crops and small grains.

Table 4. CROP ALLOCATION BY COUNTY: A COMPARISON OF VENICE TOWNSHIP SURVEY RESULTS WITH CENSUS OF AGRICULTURE DATA.

	Seneca Co.		Crawford Co.		Huron Co.		Venice Twp. Survey	
	acres	% of cropland	acres	% of cropland	acres	% of cropland	acres	% of cropland
corn	57490	31.2	98143	36.2	41120	29.4	1733	33.7
Soybeans	81916	44.4	52833	39.8	63816	45.6	2012	39.2
Wheat	31221	16.9	20883	15.7	22253	15.9	1051	20.5
Small grain (oats)	13710	7.4	10991	8.3	12551	9.0	338	6.6

Table 5. CROP ROTATION SEQUENCES USED BY 26 FARMERS IN HONEY CREEK BASIN (VENICE TOWNSHIP)[a]

3 crop sequences	4 crop sequences	5 crop sequences
ccw	ccco	cccbw
cbw (5)	ccbw(2)	ccbow
cow	ccow	cbcbw
	cbcb	cbbow
	cbcw	cwbob
	cbbw	
	cbow(6)	
	cowb	

a. The number in parentheses is the number of farmers using that rotation sequence for those rotations reported more than once. c=corn, b=soybeans, w= wheat followed by winter crop, o=oats.

Table 6. FREQUENCY OF CROPS PRECEDING AND FOLLOWING A GIVEN CROP [a]

	Percent frequency of a crop pair							
Crop	crop previous year				crop year after			
	corn	soybeans	wheat	oats	corn	soybeans	wheat	oats
Corn	24	16	58	2	24	58	8	10
Soybeans	82	7	7	4	22	7	34	37
Wheat	12	43	0	45	92	8	0	0
Oats	31	69	0	0	7	7	85	0

a. The frequency of all crop pairs in the rotation sequences shown in Table 5 were determined in order to infer and weigh cover conditions.

Table 7. MONTHLY COVER CONDITIONS BY CROP, ASSUMING CONTINUOUS CROPPING.

	JAN.	FEB.	MAR.	APR.	MAY	JUN	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.
	-Fraction of Soil Covered-											
Row Crops												
Corn fall pl.	0	0	0	0	0	.10	.40	.80	.60	.40	0	0
Corn res. le. spg. pl.	.80	.70	.60	0	0	.10	.40	.80	.60	.80	.80	.80
Soybeans fall pl.	0	0	0	0	0	.5	.20	.40	.50	.20	0	0
Soybeans res. le. spg. pl.	.40	.35	.30	0	0	.5	.20	.40	.50	.40	.40	.40
Small Gr.												
Wheat fol. by cov.	.20	.20	.20	.50	.80	.95	.50	.30	.80	.80	.80	.80
Oats fol. by wht.	-	-	-	0	.40	.95	.80	.80	0	.05	.10	.20

Table 8. LAND CONDITIONS PRECEDING AND FOLLOWING MAJOR CROPS IN HONEY CREEK WATERSHED

Previous Crop (Jan. thru Mar.)			This Crop (Apr. thru harvest)	Next Crop (Harvest thru Dec.)		
Crop	land prep.	%[a]		Crop	land prep.	%[a]
corn	fall plow	12				
	spr. plow	12				
soybeans	fall plow	8				
	spr. plow	8	corn	row crop (and oats)	fall plow	46
					spr. plow	46
wheat	winter cover phase	58	(46% of row crop)	wheat	fall plow and plant	8
oats	fall plow	1				
	spr. plow	1				
corn	fall plow	42.5				
	spr. plow	42.5				
soybeans	fall plow	3.8		row crop (and oats)	fall plow	34
	spr. plow	3.9	soybeans		spr. plow	34
wheat	winter cover phase	7.7	(54% of row crop)	wheat	fall plow and plant	33
oats	fall plow	1.9				
	spr. plow	1.9				
wheat	planted previous fall	100	wheat (75% of small grain crop)	alfalfa, clover or other legume	interseed in wheat or plant in residue	100
corn	fall plow	15		row crop	fall plow	7
	spr. plow	16	oats		spr. plow	7
soybeans	fall plow	35	(25% of small grain crop)	wheat	fall plow and plant	86
	spr. plow	34				

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[a] Percentage indicates the proportion of the subject crop area (this crop) that is found in the specified preplant or post-harvest condition.

Table 9. ESTIMATION OF MONTHLY COVER CONDITIONS FOR ROW CROPS

	Month Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.	Oct.	Nov.	Dec.
Corn	prior to corn			ground prep.; plant corn	grow corn					harvest corn		
	cf[a] .12 $\frac{0}{0}$	cf .12 $\frac{0}{0}$	cf .12 $\frac{0}{0}$							cf .21 $\frac{0}{0}$[c]	cf .46 $\frac{0}{0}$	cf .46 $\frac{0}{0}$
	cs .12 $\frac{.80}{.096}$	cs .12 $\frac{.70}{}$	cs .12 $\frac{.60}{.072}$							cs .21 $\frac{.80}{.16}$	cs .46 $\frac{.80}{.37}$	cf 46 $\frac{.80}{.37}$
	bf .08 $\frac{0}{0}$	bf .08 $\frac{0}{0}$	bf .08 $\frac{0}{0}$	1.0 $\frac{0}{0}$	1.0 $\frac{0}{0}$	1.0 $\frac{.10}{.10}$	1.0 $\frac{.40}{.4}$	1.0 $\frac{.80}{.8}$	1.0 $\frac{.60}{.6}$	w .08 $\frac{.05}{.0}$	w .08 $\frac{.10}{.01}$	w .08 $\frac{.20}{.02}$
	bs .08 $\frac{40}{.032}$	bf .08 $\frac{35}{.028}$	bf .08 $\frac{30}{.024}$							.5 $\frac{.50}{.25}$	h	
	w .58 $\frac{.80}{.46}$	w .58 $\frac{.80}{.46}$	w .58 $\frac{.80}{.46}$									
	of .01 $\frac{0}{0}$	of .01 $\frac{0}{0}$	of .01 $\frac{0}{0}$									
	os .01 $\frac{.80}{.008}$	os .01 $\frac{.80}{.008}$										
	.60	.50	.56	0	0	.10	.40	.80	.60	.45	.38	.39
Soybeans	prior to soybeans			ground prep	plant beans	grow beans			harvest beans			
	cf .43[b] $\frac{0}{0}$	cf .43 $\frac{0}{0}$	cf .43 $\frac{0}{0}$						bf .08 $\frac{0}{0}$	bf .25 $\frac{0}{0}$	bf .33 $\frac{0}{0}$	bf .33 $\frac{0}{0}$
	cs .43 $\frac{.80}{.34}$	cs .43 $\frac{.70}{.30}$	cs .43 $\frac{.60}{.26}$						h bs .08 $\frac{.40}{.03}$	bs .25 $\frac{.40}{.10}$	bs .33 $\frac{.40}{.13}$	bs .33 $\frac{.40}{.13}$
	bf .035 $\frac{0}{0}$	bf .035 $\frac{0}{0}$	bf .035 $\frac{0}{0}$	1.0 $\frac{0}{0}$	1.0 $\frac{0}{0}$	1.0 $\frac{.05}{.05}$	1.0 $\frac{.20}{.20}$	1.0 $\frac{.40}{.40}$	w .09 $\frac{0}{0}$	w .25 $\frac{.05}{.01}$	w .34 $\frac{.10}{.03}$	w .34 $\frac{.20}{.07}$
	bs .035 $\frac{.40}{.01}$	bs .035 $\frac{.35}{.0}$	bs .035 $\frac{.30}{.01}$						.75 $\frac{.40}{.30}$	h .25 $\frac{.40}{.10}$	h	
	w .07 $\frac{.80}{.06}$	w .07 $\frac{.80}{.06}$	w .07 $\frac{.80}{.06}$									
	.41	.36	.33	0	0	.05	.20	.40	.33	.21	.16	.20

---

a. Abbrev: crops: c=corn; b=soybeans; w=wheat; followed by cover crop; o=oats
practices: f=fall plow; s=spring plow with prior crop residue; h=harvest

b. Includes .02 oats

c. Key: A B $\frac{C}{D}$: A = crop/practice code; B = fraction of crop area to which crop/practice code applies
C = estimated fraction of soil covered by crop foliage or crop residue
D = weighted fraction of soil cover for crop/practice indicated (B x C)

Table 10. ESTIMATION OF MONTHLY COVER CONDITIONS FOR SMALL GRAINS AS FRACTION OF SOIL COVERED

	Month Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Wheat	winter wheat planted previous fall now dormant		growth of wheat resumes				harvest					
					interplant alfalfa clover cover		- - - →	cover emerges				
	.20	.20	.30	.50	.80	.95	.50	.30	.80	.80	.80	.80
Oats	prior to oats			soil prep plant oats	grow oats		harvest oats	assume residue on soil	plant wheat	wheat growth begins		
	[a] cf .15 $\frac{0}{0}$	cf .15 $\frac{0}{0}$	[b] cf .15 $\frac{0}{0}$									
	cs .16 $\frac{.80}{.13}$	cs .16 $\frac{.70}{.11}$	cs .16 $\frac{.60}{.10}$	1.0 $\frac{0}{0}$	1.0 $\frac{.40}{.40}$	1.0 $\frac{.95}{.95}$	.5 $\frac{.95}{.475}$					
	bf .35 $\frac{0}{0}$	bf .35 $\frac{0}{0}$	bf .35 $\frac{0}{0}$				.5 $\frac{.80}{.40}$	1.0 $\frac{.80}{.80}$	1.0 $\frac{0}{0}$	1.0 $\frac{.05}{.05}$	1.0 $\frac{.10}{.10}$	1.0 $\frac{.20}{.20}$
	bs .34 $\frac{.40}{.13}$	bs .34 $\frac{.35}{.12}$	bs .34 $\frac{.30}{.10}$									
	.26	.23	.20	0	.40	.95	.875	.80	0	.05	.10	.20

a. Abbrev: crops: c=corn; b=soybeans; w=wheat; followed by cover crop; o=oats.
practices: f=fall plow; s=spring plow with prior crop residue; h=harvest

b. Key: A B $\frac{C}{D}$: A = crop/practice code; B = fraction of crop acres to which crop/practice code applies;
C = estimated fraction of soil covered by crop foliage or crop residue;
D = weighted fraction of soil covered for crop/practice indicated (BxC)

Table 11. SYNTHESIS OF MONTHLY COVER CONDITIONS FOR ROW CROPS AND SMALL GRAINS

		Month											
		Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
	percent of class	Weighted fraction of cover											
Row Crops													
Corn	46	.276	.276	.257	0	0	.046	.184	.368	.276	.207	.175	.179
Soybeans	54	.221	.194	.178	0	0	.027	.108	.216	.178	.113	.086	.108
Row crop synthesis		.50	.46	.44	0	0	.07	.29	.58	.45	.32	.26	.28
Small grains													
Wheat	75	.15	.15	.15	.38	.60	.712	.375	.22	.60	.60	.60	.60
Oats	25	.065	.06	.05	0	.10	.238	.22	.20	0	.01	.02	.05
Small grain synthesis		.22	.21	.20	.38	.70	.95	.60	.42	.60	.61	.62	.65

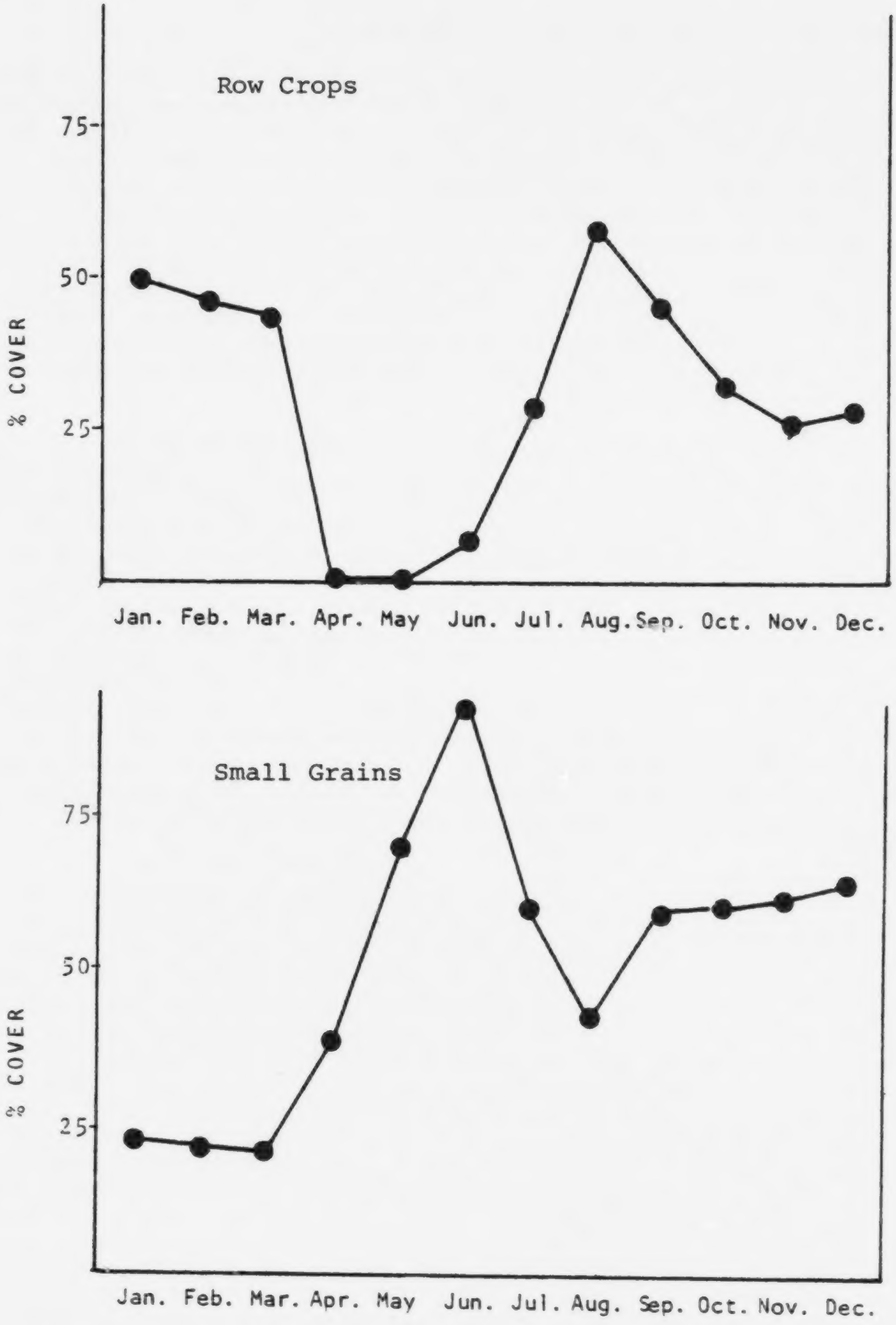

Figure 10. Estimation of monthly cover conditions for crops in Honey Creek. (see table 12)

MOISTURE ACCOUNTING IN THE SOIL MANTLE

The hydrologic (LANDS) simulation algorithms for the NPS model are driven by the process of infiltration, the rate for which is highly dependent on changes of moisture content in the soil profile. The concepualization of a surface layer of soil and an underlying soil mantle as two moisture storage compartments or zones, with variable moisture contents, is reasonable and consistent with existing theory and experience. In reality, the descending soil horizons are usually a gradation of moisture contents, complicated by varying permeabilities and textures. In general, however, the surface layer usually loses moisture much more rapidly than the underlying soils in cultivated fields, with the "plow depth" as the definition of upper layer.

The initial task in any hydrologic calibration is to develop a water balance for the test plot or watershed, preferably on an annual basis, (Eq. 30, p. 178, NPS). The most difficult aspect of this process is estimating the moisture that enters deep percolation, a storage component that is impossible to measure, except by inference. For the Honey Creek basin, however it is not unreasonable to assume that the amount of precipitation that eventually contributes to deep percolation is zero, based on the underlying aquifer conditions, the low permeability of many soils and the extensive under drainage. The changes in soil moisture storage can be measured reasonably well for small plots as were used in initial ARM model calibration, but for a watershed the size of Honey Creek this becomes a formidable task. At present, no field measurements of soil moisture are being made within the basin.

In agricultural regions of the country, a great deal of thought has gone into evaluating changes in soil moisture in order to optimize planting of crops and anticipate drought cycles as they begin to develop. One such method or model used by the U.S. Weather Service (NOAA) is the Palmer Index Analysis (Palmer, 1965), which calculates soil moisture changes based on climatological conditions and evaluates drought trends and severity. The analysis is done on a regional basis (there are 10 regions in Ohio) for the 35 week growing season from late February to early November. In this analysis, soil moisture in both the upper soil layer and underlying soil is estimated, as well as potential evapotranspiration (Thornthwaite Method) and actual evapotranspiration.

It was believed that this soil moisture modeling data would be of great value in applying the NPS model in various regions across the country, if it corrolated reasonably well in predicting actual runoff from larger watersheds, such as Honey Creek. The Palmer data for the 18-week spring runoff period in 1976, from February 29 to July 3, were evaluated in terms of the moisture budget equation, with the runoff from the Honey Creek basin estimated to be 3.16 inches, (Table 12). The weather data used in the analysis included 11 stations in north-central Ohio (Div. 02). The average precipitation compared favorably with the Tiffin daily record. The evapotranspiration and changes in soil moisture were calculated on a weekly basis, and showed a net loss of 1.82 inches of soil moisture to runoff. During the same period, the stream gage at Melmore recorded a total flow of 3.16 inches out of the Honey Creek basin. This perfect balance is certainly only a coincidence, but does reinforce the assumption of zero deep percolation in the basin. More importantly, it gives credence to the moisture accounting methods used in the Palmer model. The soil moisture changes as estimated for both surface and underlying soil are shown in Fig. 11.

An important question with respect to the NPS model calibration is how well the evapotranspiration predicted in the Palmer model compares with adjusted pan evaporation data, since both are used in the Honey Creek calibration. These pan evaporation data are gathered at the Hoyville Agricultural Research Station (Fig. 3), but only for the 7-month period April through October. A comparison of values for the period April 4, 1976, through July 25, 1976, showed poor correlation. The ratio of evapotranspiration to adjusted pan evaporation varies considerably, from 0.38 to 1.02. The estimation of this factor in the NPS model (K3) as the fraction of the watershed with deep rooted vegetation appears to be invalid in the Honey Creek basin, which has only 10.5% of the basin in woodland. In fact, it seems reasonable to apply a monthly value of K3 to better estimate the changing ratio between actual and pan evaporation.

EVAPOTRANSPIRATION

Accurate estimation of this component of the moisture accounting process is the key to successful calibration of the NPS Model, at least in a hydrologic sense. As discussed previously, the Palmer Drought Index Model, developed by NOAA, uses a modified version of the Thornthwaite Equation to calculate evapotranspiration and associated soil moisture changes in upper and lower soil layers. In the Palmer Model, the potential evapotranspiration (PE) is calculated on a weekly basis for a growing season (March through October) and on a monthly basis for the full year. A comparison of these estimated values of evapotranspiration are shown in Table 13 and 14 for the Honey Creek basin during 1976 and 1977. Also shown are average annual values from lysimeter measurements at the Coshocton agricultural research station, some 70 miles eastsoutheast of Honey Creek. These various values can be compared to the net loss, assuming no deep groundwater storage, or loss of soil moisture. For the summer months of June, July and August, all methods estimate a higher evapotranspiration than net loss, suggesting

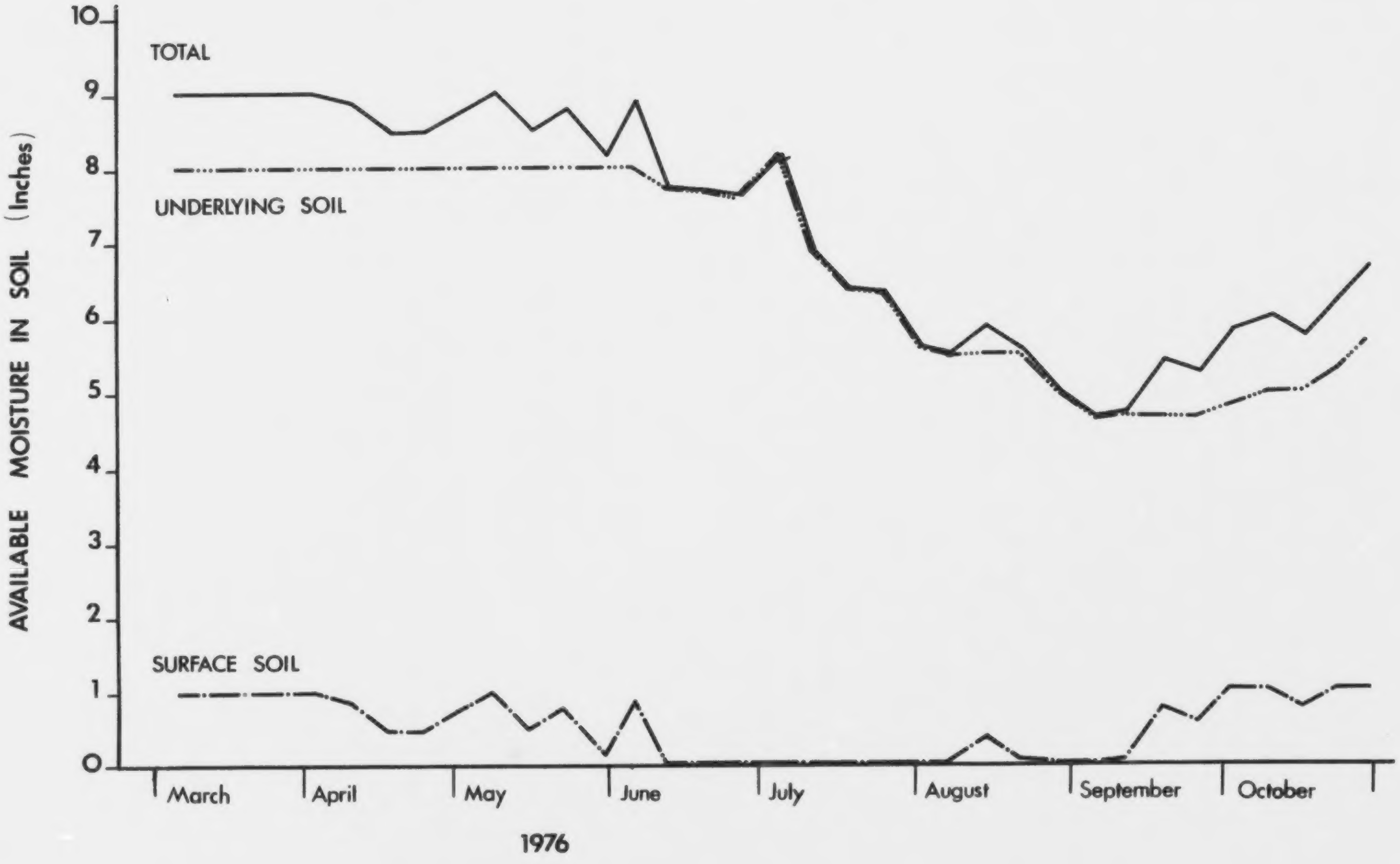

Figure 11. Palmer analysis of soil moisture, Honey Creek basin, 1976.

Table 12. WATER BALANCE ANALYSIS FOR HONEY CREEK BASIN, FEB.29 TO JULY 3,1976

MONTH	PRECIPITATION (in./mo.)			Palmer Analysis Data (NOAA) Weekly basis					RUNOFF
				P			ET	SP-(SS+SU)	(Melmore gage)
	Tiffin	Plymouth	Bucyrus	wk. no.	precip. 11 sta. in N.C. Ohio	Dates	Weekly Evapotranspiration	Soil moisture storage	
	in/mo.	in/mo.	in/mo.		in/wk.		in/wk.	in/wk.	in/mo.
(2-29)	0	0	0	1	1.9	2/29 3/6	0.27	0	0.36 (2/29)
				2	0.3	3/7 3/13	0.05	0	
MAR.	3.12	-	3.86	3	0.3	3/14 3/20	0.07	0	1.73
				4	0.6	3/21 3/27	0.31	0	
				5	0.7	3/28 4/3	0.30	0	
April	1.60	1.98	2.18	6	0.1	4/4 4/10	0.23	-0.14	0.33
				7	0.2	4/11 4/17	0.54	-0.39	
				8	0.8	4/18 4/24	0.78	+0.01	
				9	0.6	4/25 5/1	0.30	+0.26	
May	4.25	2.37	2.57	10	1.0	5/2 5/8	0.45	+0.26	0.18
				11	0.2	5/9 5/15	0.72	-0.51	
				12	1.0	5/16 5/22	0.70	+0.28	
				13	0	5/23 5/29	0.64	-0.61	
				14	1.6	5/30 6/5	0.93	+0.71	
June	3.09	4.55	4.92	15	0.1	6/6 6/12	1.25	-1.12	0.19
				16	1.3	6/13 6/19	1.32	-0.05	
				17	1.0	6/20 6/26	1.08	-0.05	
July 1-3	0.57	0.72	0.41	18	0.7	6/27	1.12	-0.47	0.37(7-1,2,3)
Totals	12.58		13.94		12.4		11.06	-1.82	3.16

P - ET - Deep perc. - Soil Moisture Storage = Runoff
(12.4)-(11.06)- (0) - (-1.82) = 3.16
3.16 = 3.16

Balance

Table 13. ANNUAL MOISTURE BALANCE, HONEY CREEK AT MELMORE, 1976

	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
Precipitation(P)												
Snowfall (as P in inches)	0.84	0.86	0.31	0.02							0.04	0.65
Total Precip. (inches)												
Tiffin daily	3.43	3.36	3.12	1.60	2.87	3.09	3.84	2.88	2.71	2.12	0.47	1.09
Tiffin hourly	3.3	3.60	3.31	2.10	4.3	3.4	3.6	2.9	3.3	2.0	0.47	1.34
Streamflow(Q)												
@ Melmore (in.)		4.35	1.73	0.33	0.18	0.19	0.13	0.08	0.06	0.22	0.18	0.13
Net Loss												
P-Q daily		-0.99	1.39	1.27	2.69	2.90	3.71	2.80	2.65	1.90	0.29	0.96
P-Q hourly		-0.75	1.58	1.77	4.12	3.21	3.47	2.82	3.24	1.78	0.29	1.21
Evaporation												
Pan @ Hoyville				6.03	6.55	8.66	8.69	6.11	5.17	2.76		
Adjusted Pan (X0.7)				4.22	4.58	6.06	6.08	4.28	3.62	2.0+		0.0^E
Evapotranspiration												
Average Annual (Estm.) Coshocton Lysimeter	1.9	2.3	3.1	3.9	5.0	5.4	5.9	4.6	3.6	2.8	1.8	1.9
Palmer Index (PE)												
Weekly			0.83	1.93	2.84	5.07	5.48	4.39	3.08	1.33		
Monthly	.0	0.12	0.84	1.74	2.94	5.08	5.46	4.37	3.08	1.27	0.10	0.0
Thornwaite Equation												
$U = 1.6(\frac{10t}{I})^a$	-	0.34	1.07	1.92	2.63	4.12	4.37	3.90	3.10	1.42	0.15	-

Table 14. ANNUAL MOISTURE BALANCE, HONEY CREEK AT MELMORE, 1977

	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
Precipitation(P)												
Snowfall (as P in inches) 3.3" snow on GD. 1/1/77	1.20	0.44	0.25									
Total Precip. (Model-rain input-moisture) (inches)	0.0	2.75	4.50	3.57	1.84	3.01	2.01	5.19	(thru 9/18) 4.48			
Tiffin-Daily	1.03	1.67	4.89	3.56	2.29	2.02	3.14	6.03	5.82			
Tiffin-Hourly	0.90	1.70	4.50	3.60	1.90							
Streamflow(Q)												
@ Melmore (in.)	0.11	1.22	2.41	1.53	0.64	0.04	0.82	0.18	0.70			
Net Loss												
P-Q Daily												
P-Q Hourly												
Evaporation												
Pan @ Hoytville				(22 days) 4.62	8.08	7.76	8.89	5.48	4.26			
Adjusted Pan (x 0.7)				3.23	5.66	5.43	6.22	3.84	2.98			
Evapotranspiration												
Average Annual (estm.) Coshocton Lysimeter	1.9	2.3	3.1	3.9	5.0	5.4	5.9	4.6	3.6	2.8	1.8	1.9
Palmer Index (PE)												
Weekly												
Monthly	0.0	0.0	0.85	2.08	4.12	4.40	5.99	4.88	3.64			

that soil moisture is being given up from storage; for the balance of the year the Palmer and Thornthwaite equations appear far more representative than the adjusted pan data or the Coshocton data. The pan data for February, March, November and December used in the NPS model were based on the Palmer values.

HYDROLOGIC PARAMETERS (LANDS)

Index Infiltration (INFIL)

Recognizing that infiltration is both spatially and temporally variable in a watershed, the NPS model uses an input parameter (INFIL) to establish an index infiltration level, equal to the mean infiltration capacity ($\bar{f}$) when the current storage of soil moisture in the lower zone (*LZS*) is equal to the index level of moisture storage (*LZSN*) for the lower zone, or $LZS/LZSN = 1$. This parameter is a function of soil characteristics, such as cohesiveness and permeability, and is estimated to vary by two orders of magnitude, (0.01 to 1.0 in./hr).

With a cellular data base such as exists in Honey Creek, it is possible to apply specific data on infiltration capacity variability by soil series distribution within the watershed, or even evaluate varying infiltration by soil horizon. The computer files show that the majority of soils in Honey Creek have a surface permeability with a lower range of from 0.2 to 0.6 in./hr and that for many soils, the "B" and "C" horizons have substantially lower values. It is recommended that a classification system be devised for sorting out the major groupings of soils by infiltration rates through the full profile, with consideration given to cover conditions, because infiltration can be much greater with certain cover types.

Interflow (INTER)

As described earlier in the discussion of types of drainage systems in Honey Creek, the existence and efficiency of tile underdrains in much of the cropland of the basin will radically alter the movement of water through the soil mantle as interflow. The use of one value for interflow (such as 3.0, recommended in Figure 35, NPS) is not suitable for this basin, and in fact various drainage classes should probably have different values. A time dependency should also be included, such as time since start of rainfall.

The concept of partial area hydrology, as originally proposed by Betson (1964) and developed by others (Dunne, 1969, 1976) may have great applicability in developing better algorithms for interflow. Generally recognized by most research hydrologists as a more accurate description of runoff mechanisms in humid regions, this theory proposes that only a small portion of some watersheds actually produce runoff from a storm, as described by Dunne (1975).

Although the Honey Creek basin is a humid region, it is also highly disturbed and is dissimilar from the wooded catchments Dunne and others have studied. With the extensive underdrain system, however, it is likely that Honey Creek produces varying amounts of surface runoff (and interflow) from distinct and spatially definable portions of the watershed. It is likely that under all but the most severe storms, the hydrograph produced at Melmore (and the pollutants carried with it) is generated by runoff from only a fraction of the land surface in the basin.

The task at hand is to recognize where and how saturated zones occur within the watershed, because the runoff-producing zone will vary both during and between storms. In fact, it has been found that the saturated area will expand during a storm, as the water table rises to intersect the surface. The occurrence of this condition will be a function of the factors that distinguish the various drainage classes, plus soil moisture and precipitation.

Consider the erosional mechanisms that might exist at the land surface under saturation conditions. The soil particles disturbed would move with overland flow as soon as saturation occurred. With continuing precipitation, the saturated zone would increase and a greater depth of water would exist over much of the saturated zone, contributing directly to runoff but insulating the land surface from the erosional impact of the raindrops. The moving film would, of course, possess the energy to suspend and transport material, but the border area at the expanding saturated zone would undergo substantially greater erosion mechanisms. Thus the volume of runoff would continue to increase over the period of continuing precipitation, but the pollutant concentration of the runoff would increase and then decrease. This is exactly the chemograph-hydrograph relationship that has been observed in the Honey Creek basin and many others, (Cahill, 1976).

POLLUTANT GENERATION PARAMETERS (QUAL)

The QUAL subroutine algorithms utilize several parameters that reflect the pollutant generating mechanisms of erosion and transport. It is believed that some of these could be modified and improved upon for the Honey Creek basin.

Rainfall Kinetic Energy (JREP)

This exponent of the soil splash equation is intended to approximate the relationship between rainfall intensity and incident energy to the land surface for the production of soil fines. Based on various investigations, NPS authors concluded that soil splash is proportional to the square of the rainfall intensity, so the a value of 2.0 would be reasonable for JRER in equation (9), NPS. Because the major sediment producing storms in Honey Creek are in the early spring and not the intense summer thunderstorms, it is felt that the actual kinetic energy associated with a given storm should be considered in evaluating the sediment generation mechanism. The estimated annual R for this part of Ohio is 130 (AR, 1975) but it is obvious from the chemographs, hydrographs and mass transport estimates developed for Honey Creek that the erosive force associated with the storms of late winter and early spring are far more important in soil particle transport. In fact, although storms "B" and "M" are almost equal in R values and total storm energy, storm "B" produced over 14 tons of suspended solids whereas storm "M" produced a tiny fraction of that amount, (see Table 15, page 53).

The reason, quite simply, is that not only has the soil particle been displaced and brought into suspension by the rainfall impact on bare soil, but the ground surface is sufficiently saturated in wetter portions of the basin to allow immediate transport with the overland film flow (or in microrelief channels). Thus a storm such as "B", in which 9 hours of precipitation, ranging from 0.1 to 0.3 in./hr, was followed by 0.5 in./hr intensity during the last hour, resulted in what was the highest concentration of suspended solids (and total phosphorus) observed during the entire year. What part the variation in precipitation intensity during the storm played as compared with the saturated ground conditions is yet to be determined, but it would appear that antecedent moisture is a far more significant determinent than kinetic energy of rainfall. Cover appears to be a secondary factor, since this major runoff producing event occurred prior to spring plowing, with row crop cover averaging about 50% far more than subsequent periods of precipitation.

Erodability (KRER)

Because this parameter is intended to include consideration of the intrinsic erodability of a given soil, it is related to the "K" factor in the U.S.L.E.. The K factor, of course, is estimated based on texture properties of a soil, as well as structure, organic matter content, permeability and clay mineralogy. For Honey Creek, the spatial distribution of K factors are available and can be calculated exactly for any sub-basin or the basin as a whole. For the various drainage classes, appropriate K values can also be developed from the LRIS data file. It is suggested that the KRER term be considered as (A K), to allow for parameter calibration while maintaining the exact K value.

Soil Fines Transport

This is perhaps the weakest link in the NPS model, with the development of the JSER exponent and the KSER coefficient requiring substantial improvement. Limited experience in model calibration thus far suggests a narrow range of values for JSER (1.6 to 2.0), with tremendous variation found in KSER (0.01 to 5.0).

It is believed that too many variables are being included in this one basic coefficient, making the application of the NPS model to large, more complex watersheds something of a "black box" affair. Within Honey Creek, it is possible to develop a set of statistics on combinations of slope, length, particle size and surface roughness (using land use and cover factors), but the weighing of these ingredients is a task that requires a great deal of thought. The coefficient KSER represents, in effect, the potential of a particle which has been brought into suspension to remain in the fluid and move to a channel where it will be transported.

Given the applicability cf partial area hydrology, however, with an expanding zone of runoff producing saturated land and an expanding "erosion zone" at the edge, the KSER term could represent a function of the areal increase.

SECTION 7

MODEL CALIBRATION

The period of record that exists for Honey Creek at Melmore includes some 20 months over 2 years with some severe ice interference during the winter of 1977. The NPS model was calibrated on 1976 data and verified with the 1977 data. These two years are very different in terms of hydrologic events and their distribution. These differences will be apparent in the subsequent discussion. In spite of the limitations of the two data sets, the calibration will proceed as outlined.

1976 - RECORD OF HYDROLOGIC EVENTS

The peculiar feature of this year is that after the late winter-early spring runoff period, (February 10 to March 10) there was only one runoff event of any consequence throughout the balance of the entire year. (Table 15). This 30-day period of runoff comprised the major sediment and nutrient transport period for the year. 81% of the total phosphorus and 89% of the total sediment moved out of the Honey Creek basin (Table 16). For this reason, special emphasis was given to this period. Although it is characteristic of this region to have the major runoff events during the early spring with summer storms having little runoff, this year is an extreme case.

Figure 12 shows a semi-log plot of flow during the period in question, with the initial runoff event (A) caused by snow melt on frozen ground. The second event (B) was caused by heavy rains (1.81 in.) on ground heavily saturated by the preceding snowmelt, compounded by thawing ground (see Soil Temperature, Fig. 13) and warming weather. The resulting runoff contained the highest suspended solids concentration (1131 mg/l) and total phosphorus (1.82 mg/l) of the year. The patterns of suspended solids and particulate phosphorus are almost identical, with both peaking slightly before the hydrograph peak (Figures 13 and 14). The nitrate concentration does not vary dramatically over the storm hydrographs, with slight dilution effects at the peak runoff. The nitrate increase on the recession curve of storm "B" suggests tile flow input. The highest nitrate (Fig. 15) values occur later in the year during the drier periods. Ammonia peaks are observed during the snow melt event with subsequent peaks on the recession curve of storm "D", possibly as a result of tile flow dominance. It should be noted that the ammonia values

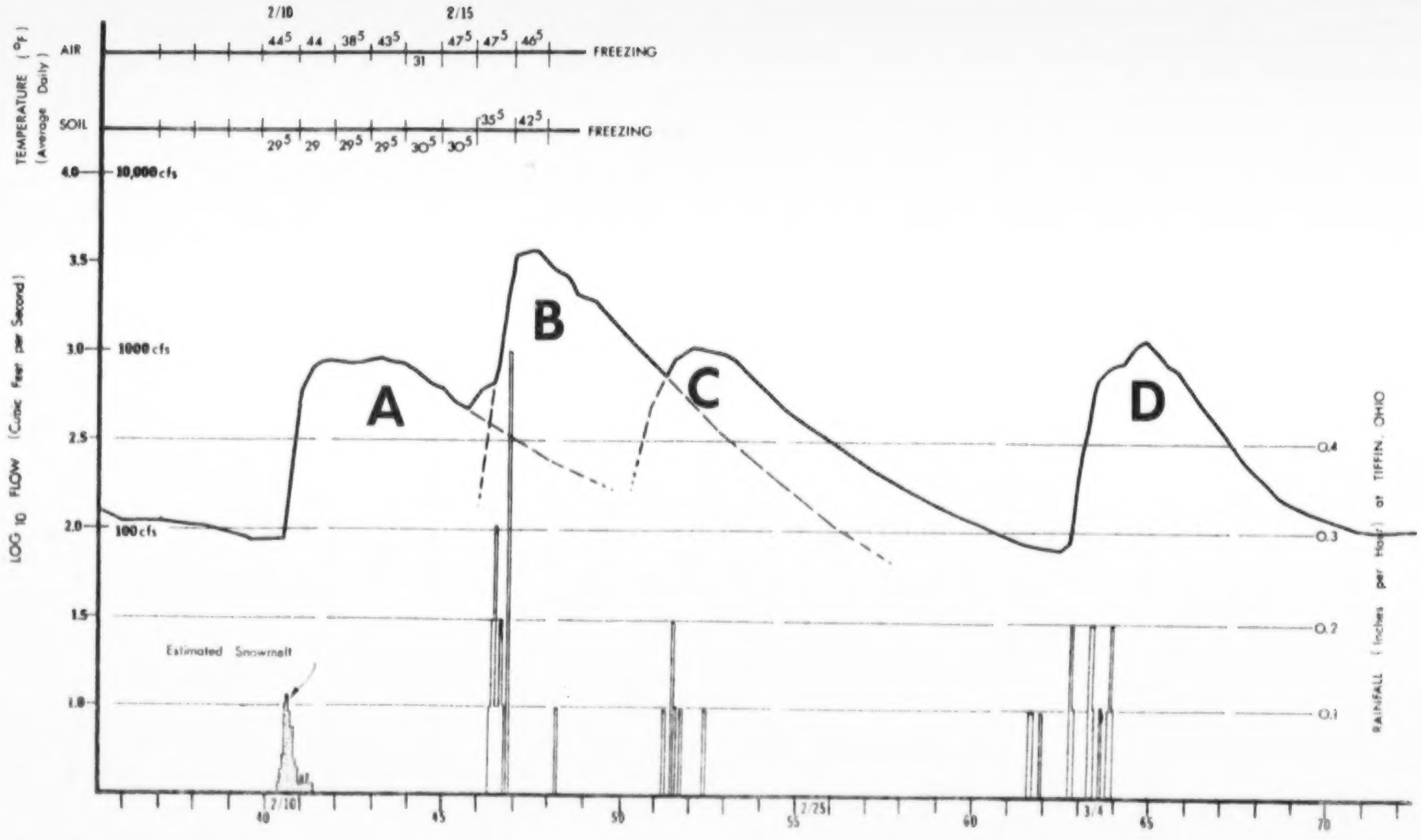

Figure 12. Hydrograph of Honey Creek at Melmore, Spring, 1976. Includes precipitation, air and soil temperature.

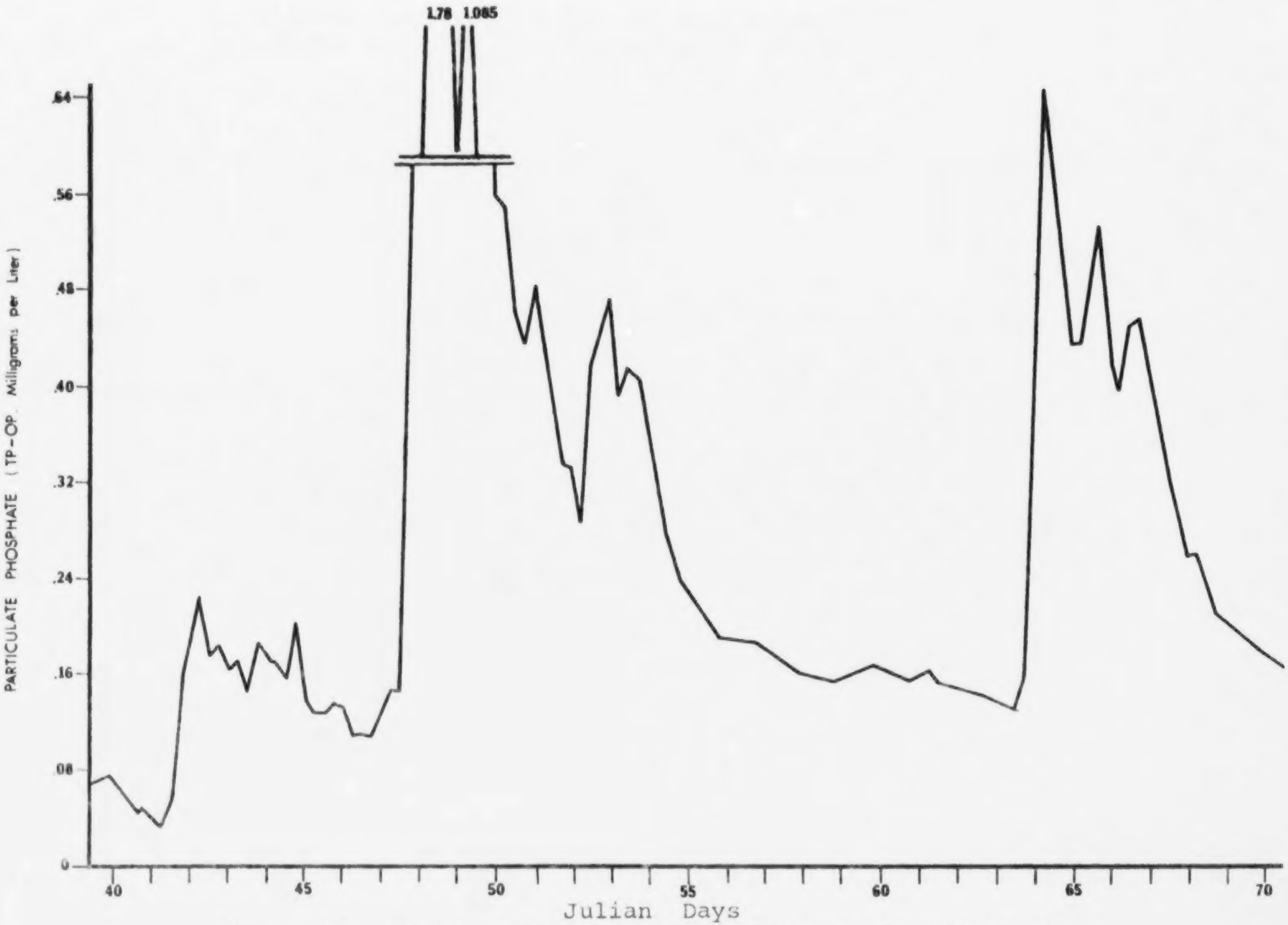

Figure 13. Particulate Phosphate - February Runoff, 1976.

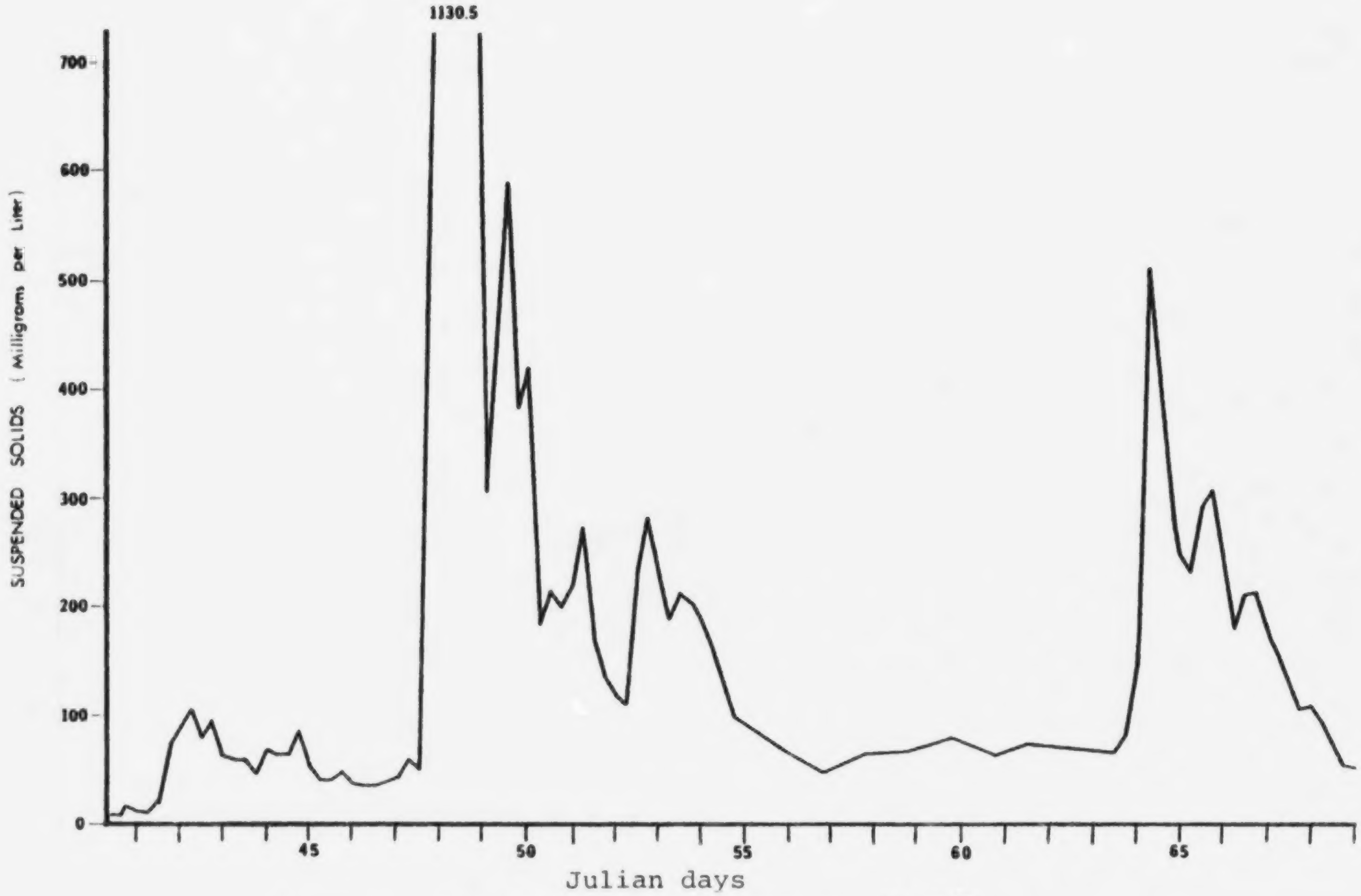

Figure 14. Suspended Solids - February Runoff, 1976.

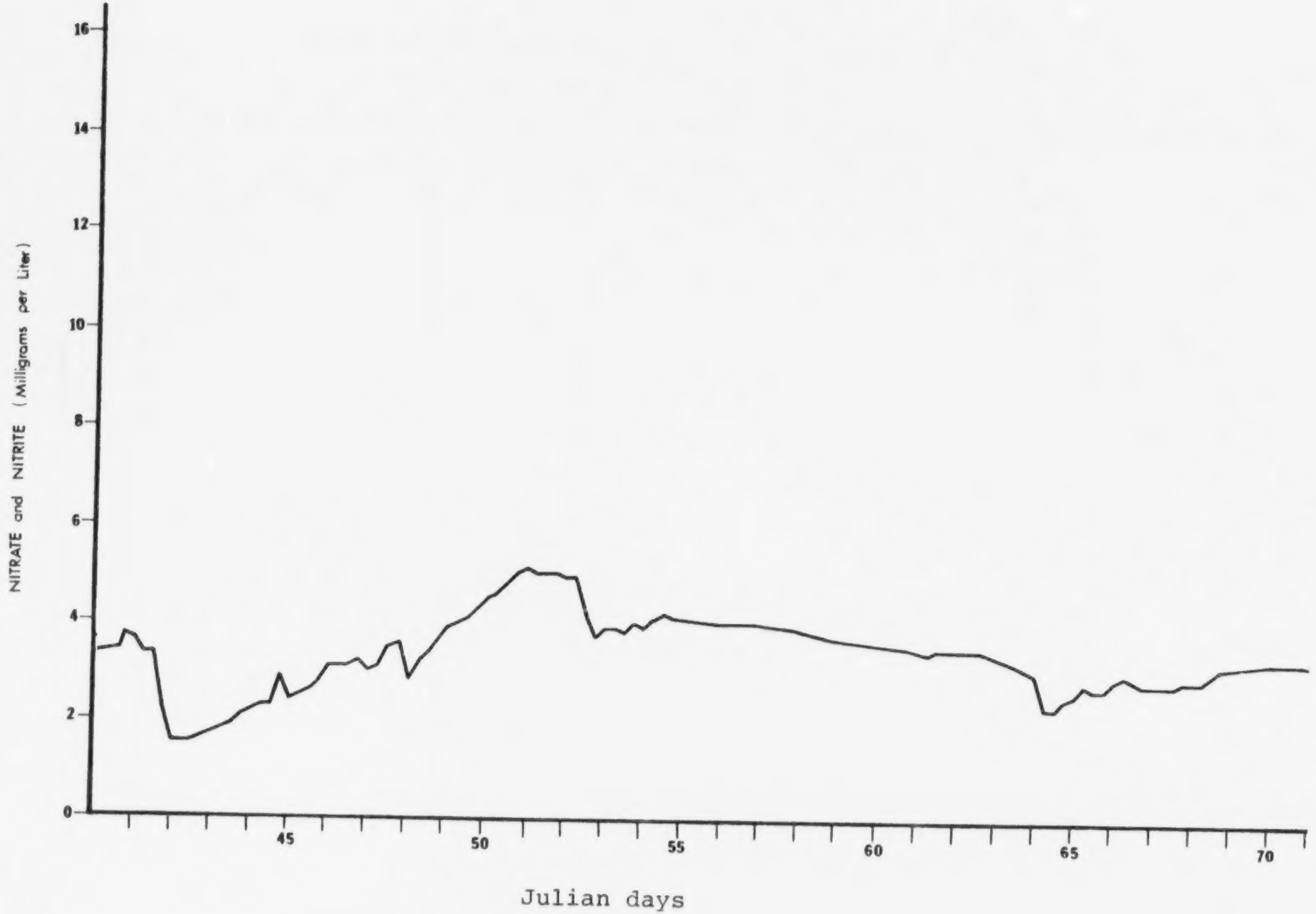

Figure 15. Nitrate and Nitrite - February Runoff, 1976

Table 15. MAJOR STORM EVENTS IN HONEY CREEK BASIN, 1976
(Melmore Gage Record)

Storm No.	Julian Day	Runoff Date(s)	No. of Hyd. Pks.	Q Max. (cfs)	TP Max. (mg/l)	SS Max. (mg/l)	Rainfall (in./day)				Period Between Major St	
							Dates	Tiffin	Plymouth	Bucyrus	No. of days	Total Rain
											36	3.47 (1-1 to 2-5)
76A 76B 76C	41	2/10 thru 2/27	3	947 4101 1125	1.82	978	2/6 2/16-19 2/22-23	0.80 1.95 0.57	0.58 1.95 0.91	0.70 2.15 0.75		
											7	T
76D	64	3/4 thru 3/8	1	1279	0.70	507	3/2-5	1.69	-	1.77		
											5	0
76E	80	3/20	1	449	0.77	383	3/11-17	0.59	0.85	0.93		
											4	T
76F	83	3/28	1	134	0.26	126	3/20-21 3/27-28	0.25	0.23	0.33		
											49	3.15
76G	140	5/19	1	68	0.22	53	5/15-18	1.90	0.92	0.81		
											10	0.03
76H	152	5/31 thru 6/4	2	83 115	0.95	706	5/29-4	1.61	1.56	1.63		
											14	0.46
76I	172	6/19 thru 6/23	1	74	0.27	88	6/19-21	0.70	1.30	1.77		
											1	T
76J	177	6/24 thru 6/27	1	85	0.25	81	6/23-25	1.07	1.04	0.83		
											3	0
76K	182	6/30 thru 7/4	1	99	0.52	209	6/29-7/2	0.78	1.03	1.09		
											4	0
76L	192	7/10	1	74	0.36	75	7/7-8	1.35	0.77	2.79		
											12	0.16
76M	205	7/23 thru 7/24	2	90 109	0.67	297	7/21-24	1.62	1.40	2.15		
											12	0.20
76N	221	8/8 thru 8/10	1	99	0.44	134	8/6-9	1.34	1.19	1.83		
											2	0
76O	228	8/15	1	48	0.53	269	8/12-16	0.75	0.52	3.14		
											10	0
76P	243	8/30 thru 9/3	1	46	0.99	35	8/27-9/2	.83	0.83	0.19		
											14	0.52
76Q	272	9/28 thru 9/29	2	109	0.51	152	9/17-22 9/26-28	1.36 0.72	1.94 0.78	0.56 1.40		
								20.23			3	0.02
											94	3.68 (9/30 to 12/3
							1976 total rainfall = 31.92 in.				280	11.69

Table 16. COMPARISON OF MASS TRANSPORT 1976

	Late Winter Storm Period Feb. 10 to Mar. 10	Annual Total	%
Total Phosphorus (metric tons)	32.7	40.4	81%
Mean Concentration (mg/l)	0.65	0.48	
No. of Samples	73	478	
Suspended Solids (metric tons)	16,846	18,985	89%
Mean Concentration (mg./l)	337	227	
Total Flow ($m^3 \times 10^7$)	4.99	8.37	

shown are extremely high for a natural stream system ($\geq$ 2 mg/l), especially during periods of greater flow. The conductivity is a mirror image of the log flow, indicating little or no input of groundwater into this flow, with slightly higher dissolved solids levels in the snowmelt runoff. The orthophosphate shows peaks during the snowmelt of event A and on the recession curve of storm C., but otherwise remains fairly constant over the period.

INPUT DATA ADJUSTMENTS

As in any model calibration study, the necessary input data are seldom in the exact form desired. There are also data gaps which must be estimated or ignored. In the Honey Creek basin the available meteorologic record leaves much to be desired, especially during 1976. The adjustments made in this model calibration are described here for future reference, so that the reader is aware of what limitations may apply to the calibration results.

Snowmelt

No record of solar radiation within a reasonable distance of the Honey Creek basin for use in the NPS snowmelt algorithm is available. Because the snowmelt-ground thaw period is so critical in terms of runoff and sediment transport, the calculation of snowmelt was done "by hand," based on the record of snowfall, snow on ground and air temperature at Tiffin. During winter months, the total accumulation of snowmelt was calculated, based on 0.10 inches of precipitation per inch of snowfall as equivalent moisture value. This total moisture storage was input as precipitation during the period of snowmelt, in proportion to the daily snow-on-ground reduction. The actual observation of this moisture as runoff from the basin appeared to have been delayed until actual ground thaw for both years, but it should be noted that the stream flow stage record was subject to ice interference during the initial thaw period, and so the correlation between snowmelt and runoff should be viewed with caution.

Precipitation Record

It would be ideal to have three or more well distributed continuous recording rainfall gages distributed throughout a basin the size of Honey Creek for NPS model input data. Unfortunately, no such network yet exists, although one is planned. For the period of record, three daily recording stations that bracket the watershed--Tiffin, Bucyrus and Plymouth--have been compared and indicate that the Tiffin daily gage is representative for most major storm events, with the exception of several summer storms. Tiffin also has an hourly record produced at a separate station (Water Works), but this record is not continuous and is rounded off to tenths of an inch. This is the only hourly precipitation record available for model calibration from February 1976 through April 1977. At that time a continuous recording instrument was established by the Heidelberg College

River Laboratory at Tiffin. Also, the hourly record at Tiffin is absent for most of March 1976 and had to be synthesized from the Fremont hourly record for distribution and the Tiffin daily for total amount.

THE NPS MODEL "SCALE" PROBLEM

Simply put, the QUAL sub-routine of the NPS model is designed to simulate pollutant washoff from land areas in small catchments, where the subsequent time of pollutant travel in the channel system to the point of flow measurement, as well as chemical sampling, is quite small as compared to the time of overland flow and/or interflow. The application of the full model (and not just the hydrologic or LANDS sub-routine) to large basin systems requires the development of methods by which this "time of travel" can be accounted for in analyzing downstream chemographs and hydrographs, or conversly in using these data for model calibration and verfication.

Before a discussion of alternatives, let us consider several pieces of knowledge that will have a bearing on these alternatives. Also, the thrust of the current work effort should be acknowledged as the transition of detailed research modeling methodologies to broader management evaluation of water quality improvement strategies. This perspective will also have a bearing on alternatives.

PERTINENT KNOWLEDGE

The relationship of chemograph to hydrograph for pollutants such as suspended solids and total phosphorus has been observed on various watersheds (Cahill et al., 1974; Baker, 1973), with the same general relationship holding true: the peak of the chemograph always precedes the hydrograph peak.

The movement of storm runoff in natural channels has been studied intensively during the past 50 years, under varying storm, channel, gradient and precipitation conditions, with most investigators concluding that the flood wave, or hydrograph, moves through the channel system faster than the fluid velocity.

The theory of "partial area" hydrology leads to the conclusion that the runoff that comprises the hydrograph (and its resulting pollutants) has come from only a portion of the watershed. The land area producing this surface runoff is a function of soil moisture, permeability and proximity to channel; it is not defined by the same considerations (texture, slope,) as would normally be used in defining "critical erosion areas."

There is little question that points one and two hold true for the Honey Creek basin; point three is only hypothetical at this time and might be evaluated on an initial basis by comparing precipitation and runoff for different storm events (Table 17).

Table 17. PRECIPITATION - RUNOFF COMPARISON, HONEY CREEK BASIN

1976 STORMS

Storm	Precipitation Input (in.)	Runoff Output (in.)	Base Flow (in.)	$\frac{\text{Net runoff}}{\text{Rainfall}}$ (%)
A	0.90	0.73	0.13	109%
B	2.10	2.48	0.14	
C	0.60	1.09	0.10	
D	1.40	0.99	0.20	56%
E	0.60	0.37	0.10	45%
F	0.25	0.06	0.03	12%
	5.85	5.73		

Assuming uniform precipitation over the basin, the first six storm events for 1976 are compared (with base flow estimated) and indicate that during the initial runoff period in February (storms A, B and C) virtually all the precipitation that fell in the watershed ran off shortly thereafter from all land areas. As the year progresses (and saturated or near saturated surface areas decrease rapidly) the volume of runoff to rainfall decreases remarkably, to a small fraction of the basin possibly contributing runoff. By the time of the late spring and summer storms, many of which are equal or greater in magnitude that the February storms, the input of one to two inches of precipitation causes barely a ripple in the basin. If the theory of diminishing response area does not hold true, then one would conclude that the basin functions as a giant sponge, soaking up precipitation and returning it as evapotranspiration over a long period of time. Although this mechanism of moisture storage is certainly operational in the basin, it is likely that something similar to a "partial area" hydrologic response is primarily responsible for the seasonal variability in Honey Creek basin hydrology.

INITIAL NPS MODEL CALIBRATION

Although recognizing the specific characteristics of hydrologic response and runoff characteristics of the Honey Creek basin, as well as the limitations of the NPS model, it was believed important to first follow the procedures recommended for model calibration and evaluate the model in its present form. This section documents those steps and the results of that calibration.

The 4 month spring-summer period of 1976, (April-July) was initially selected for hydrologic calibration, because it represented a period of substantial precipitation (13.4 in.) and very little runoff (0.83 in.), a characteristic of this type of watershed that must be understood. Pan evaporation data were also available for this period, with data collection beginning at the Hoytville station (Fig. 3) on April 1. Remember that during calendar year 1976, most of the runoff and sediment transport out of the basin occurred during February and March, preceding this initial calibration period. The focus during these initial runs was on moisture accounting, especially the evapotranspiration loss. This approach, however, proved unworkable, as the following paragraph describes.

The NPS model trial run results are shown in Table 18, with the monthly precipitation and runoff at the Melmore gage shown for comparison. Initial parameter selection was based on recommended values from the manual or basin characteristics. It was also assumed during these initial runs that the only land use in the basin was agriculture (Runs 3-11). The initial runs indicated that the evaporation input data were expressed improperly, with Table 24 (NPS) showing values expressed in hundredths of an inch,

Table 18. INITIAL HYDROLOGIC CALIBRATION OF NONPOINT SOURCE MODEL, 1976

Month	Tiffin Hourly Actual Precip. (in.)	Melmore Gage Actual Flow (in.)		MODEL TRIAL RUN NUMBER													
				3	4	5	6	7	8	9	10	11	12	13	14	15	16
				-	Cropland only			-	-	-	-	-					
Feb.	3.60	4.39	Monthly Flow (inches)										0.86	2.07	2.02	1.91	3.18
March	3.31	1.69											0.41	1.34	1.09	1.14	1.18
April	2.10	0.29		1.35	0.85	0.78	1.09	1.04	0.86	0.59	0.57	0.56	0.24	0.49	0.29	0.26	0.26
May	4.30	0.18		2.08	1.93	1.96	1.48	1.31	0.64	0.19	0.14	0.17	0.61	1.31	0.71	0.67	0.67
June	3.40	0.18		-	1.90	1.92	1.38	1.07	0.32	0.14	0.10	0.19	0.55	0.96	0.55	0.58	0.57
July	3.60	0.12		-	2.42	2.55	1.42	1.10	0.24	0.15	0.09	0.23	0.60	1.02	0.38	0.49	0.49
August	2.90	0.08												0.94	0.27	0.39	0.40
Sept.	3.30	0.05												0.98	0.25	0.36	0.36
Oct.	2.00	0.04												0.63	0.14	0.21	0.21
Nov.	0.47	0.04												0.28	0.04	0.07	0.07
Dec.	1.34	0.02												-	0.04	0.21	0.21
Totals	30.32	7.38			7.10	7.21	5.37	4.52	2.05	1.08	0.90	1.15			5.87	6.29	7.6
MODEL PARAMETERS																	
LANDS																	
INTER				3.0	0.5	3.0	-	-	-	-	-	-		-	-	-	-
NN				0.44	-	-	-	-	-	-	-	-	-	-	-	-	-
NNI				0.22	-	-	-	-	-	-	-	-	-	-	-	-	-
KI				1.0	-	-	-	-	-	-	-	-	-	-	-	-	-
EPXM				0.1	0.05	0.1	-	-	-	-	-	-	-	-	-	-	-
UØSN				1.0	-	-	-	-	-	-	-	-	-	-	-	-	-
IRC				0.5	-	-	-	-	-	-	-	-	-	-	-	-	-
L				300	-	-	-	-	-	-	-	-	-	-	-	-	-
LI				400	-	-	-	-	-	-	-	-	-	-	-	-	-
PETMUL				0.5	1.0	0.5	-	-	-	-	-	-	-	-	1.0	-	-
K24L				0.05	-	-	-	-	-	-	-	-	-	-	-	-	-
LØSN				8.0								12			8		
INFIL				0.4	-	0.2	0.4	-	-	-	0.05	-	-	-	-	-	-
SS				0.02	-	-	-	-	-	-	-	-	-	-	-	-	-
SSI				0.02	-	-	-	-	-	-	-	-	-	-	-	-	-
K3				0.1	-	-	-	0.5	-	-	-	-	-	-	-	-	-
KK24																	
UØS				1.0	-	-	-	-	-	-	-	-	-	-	-		2.5
LØS				8.0	-	-	-	-	-	4.0	-	-	4.0	12	12	15	15
SGW				0.5	0.0	-	0.5	-	-	-	-	-	-	-	-	-	-

Table 18.(cont'd.) INITIAL HYDROLOGIC CALIBRATION OF NONPOINT SOURCE MODEL, 1976

Month	Tiffin Hourly Actual Precip. (in.)	Melmore Gage Actual Flow (in.)	17	18	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Feb.	3.60	4.39	3.60	4.22	4.59	4.64	4.18	4.19	4.28	4.29	4.60	4.20	3.78	3.31	2.96	3.32	3.29	4.05
March	3.31	1.69	1.10	2.24	2.33	2.40	2.44	2.43	2.27	2.31	2.31	2.3	2.1	2.09	1.79	2.09	2.13	2.19
April	2.10	0.29	0.29	0.48	0.50	0.54	0.58	.58	.50	.50				0.42	0.39	0.43	0.41	0.42
May	4.30	0.18	0.71	0.63	-	0.67	0.70	.70	.68					0.58	0.59	0.59	0.50	0.57
June	3.40	0.18	0.57	0.57	-	0.58	0.60	.60	.54					0.44	0.45	0.45	0.37	0.39
July	3.60	0.12	0.39	0.41	-	0.45	0.46	.46	.46					0.36	0.37	0.37	0.30	0.28
August	2.90	0.08	0.27	0.30	-	0.32	0.32	.32	.46					0.38	0.39	0.39	0.34	0.23
Sept.	3.30	0.05	-	0.28	-	0.31	0.27	.27	.54					0.43	0.44	0.43	0.36	0.20
Oct.	2.00	0.04	-	0.17	-	0.18	0.16	.16	.37					0.31	0.30	0.29	0.27	0.12
Nov.	0.47	0.04	-	0.05	-	0.08	0.07	.07	.24					0.24	0.23	0.21	0.24	0.05
Dec.	1.34	0.02	-	-	-	0.27	0.25	.25	.88					0.84	0.75	0.67	0.84	0.18
Totals	30.32	7.38	-	9.35	-	10.44	10.04	10.04	11.2					9.39	8.65	9.22	9.04	8.68
MODEL PARAMETERS																		
LANDS																		
INTER			3.0	1.0	-	3.0	-	-	-	-	-	-	-	2.0	-	-	-	3.0
NN			0.44	-	-	-	-	0.15	-	.05	.15	-	-	-	-	-	-	-
NNI			0.22	-	-	-	-	0.10	-	-	-	-	-	-	-	-	-	-
KI			1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EPXM			0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UZSN			1.0	-	-	1.5	1.0	-	-	-	.8	-	-	1.0	-	-	-	-
IRC			0.5	-	-	-	0.7	-	0.5	-	-	-	-	0.4	-	-	-	-
L			300	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LI			400	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PETMUL			1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
K24L			0.05	-	-	-	-	-	-	-	-	-	0.25	0.05	-	-	-	-
LZSN			8.0	-	-	-	-	-	-	-	-	-	-	-	10.	8	-	-
INFIL			0.05	-	-	-	-	-	-	-	-	-	-	.03	-	-	.02	-
SS			0.02	-	-	-	-	-	-	-	-	-	-	0.01	-	-	-	-
SSI			0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
K3			0.5	-	-	-	-	-	.1	-	-	-	-	-	-	0.2	0.1	0.5
KK24			0.5	-	-	-	0.8	-	.5	-	-	-	-	0.4	-	-	-	-
UZS			1.0	3.0	-	4.0	3.0	-	-	-	-	-	-	2.0	-	-	-	3.0
LZS			9.0	12.0	-	-	-	-	-	-	-	-	-	10.0	-	-	-	-
SGW			0.5	-	-	-	-	-	-	-	-	0.1	-	0.5	-	-	-	-

but the model reading thousandths. Thus in Run 6, the evaporation data were multiplied by 10. It readily became apparent that it would be necessary to allow for much greater evapotranspiration in the basin than the model was providing, and so in Run 7 the parameter K3 was increased to 0.5. Next, in Run 8, the raw pan evaporation data were artifically multiplied by 1.5, and in Runs 9 and 10 the parameter INFIL was first increased with decreased LZS, and then reduced. For Run 11, the evaporation data were used in their correct form (pan evap. x 0.7) and the LZSN was increased to facilitate greater uptake by root systems. The total runoff for the period, as well as the monthly runoff figures, was not within an acceptable range, but virtually all of it occurred as base flow. The total runoff for the 4 months (1.15 in.) was still higher than actual runoff (0.83 in.), but it was felt that the full calendar year, with all land use categories included, should be run. This was done beginning with Run 12, and it became apparent that the heavy runoff experienced in February and March could not be effectively simulated unless the initial storage in both the lower and upper zones was significantly increased. By Run 16, the annual runoff was correct, but the runoff in late winter period was still low and that of the summer too high.

The precipitation data, especially snowmelt, were reexamined and compared with the daily records for the three stations surrounding the watershed. Some improvement was made for February and August, but it was thought that the only way to produce the combined snowmelt, thaw and precipitation of February was to "load up" the initial UZS. This produced Run 18, with February increased to a satisfactory level but the balance of the year too high.

Because 89% of the suspended solids for the year are flushed from the basin during the 30 day period of February 10 to March 10, it was decided to focus on refining this period, comprised of the four runoff events described previously. The mass transport occurring for these events is summarized in Table 19, with storm "A" the "byhand" simulated snowmelt runoff. Refinements were made to the shape of the recession curves (IRC and KK 24), and the overland flow component increased by significantly decreasing the Manning friction factors, a reasonable adjustment for February and March, but not the balance of the year. By Run 24, it was believed that the initial hydrologic calibration was acceptable for the spring runoff period, although the annual total (11.2 inches) was still too high. The QUAL sub-routine was run using the LANDS inputs for Run 24, with the three storms in February and one in March used for mass transport comparisons.

All four storms were low in terms of sediment production, and so in Run 25 the overland flow component was increased by reducing the Manning "N" for pervious surfaces to 0.5 (frozen ground, untilled). This resulted in a very minor increase in suspended solids, so Run 251 increased KSER from 1 to 3, pro-

Table 19. MASS TRANSPORT ESTIMATES FOR 1976 STORMS

Storm	Transport period from		to		Total hours	Total Flow cfs-days	Total Flow in.	Base Flow	Total Precipation Snowmelt/Rain	Total Susp. Solids tons	TPP # (tons)	Q Max. cfs
Major Storms												
A	2/10	1800	2/15	1800	120	2,920.	0.73	0.13	0.90/0	478	1.26	723
B	2/15	2400	2/21	0700	127	9,920.	2.48	0.14	/2.10	14,899.	26.52	3440
C	2/21	1300	3/2	1300	240	4,360.	1.09	0.25	/0.60	1,613.	3.26	1124
D	3/3	1900	3/11	1900	192	3,980	0.99	0.20	/1.40	2,269.	4.20	1280.
						21,180.	5.29		5.00	19,259.	35.24	
Minor Storms												
E	3/19	1900	3/25	1900	144	1470	0.37	0.10	0.60	671		449.
F	3/27	1900	3/29	1900	48	256	0.06	0.03	0.25	65		134.

ducing good calibration for storm "B", the dominant event, but poor calibration for the other three storms. This run simulated 72% of the actual suspended solids runoff for the period, with the simulated flow for storm "D" still too high.

In Runs 26, 27 and 28, changes were made in LANDS parameters (NN,UZSN) to increase the overland flow component. Storm "B" increased sediment delivery greatly, but the other storms showed little sensitivity. Runs 29 through 33 reflect final adjustments to both LANDS and QUAL parameters simutaneously, in order to balance both the runoff and sediment production.

The final calibration summary is shown in Table 20, and gives very good overall mass transport simulation. However, while the total runoff and pollutant mass transport simulations were being refined in Runs 24 through 33, it was apparent from CALCOMP plots of the output that the timing of both runoff and sediments was far too rapid. Figure 16 shows the hydrograph simulation without routing for February-March, 1976, with the extreme peaks representing the actual NPS model output for Run 33 at Melmore, done as one single basin. It is obvious that the time delay of both fluid and particles in moving through the watershed must be considered in order to replicate the chemographs and hydrographs observed at Melmore.

Table 20. NPS MODEL CALIBRATION SUMMARY - 1976

	1976 Actual Data		1976 (Run 3311 Simulated Data	
	Flow (inches)	Suspended Solids (tons)	Flow (inches)	
JAN.	-	-	-	-
FEB.	4.39	16,965.	4.05	16,806.
MAR.	1.69	3,115.	2.19	3,009
APRIL	0.29	55.	0.42	428
MAY	0.18	155.	0.57	499
JUNE	0.18	194.	0.39	106
JULY	0.12	166.	0.28	58.3
AUG.	0.08	62.	0.23	11.8
SEPT.	0.05	30.	0.20	11.6
OCT.	0.04	4.	0.12	13.6
NOV.	0.04	2.	0.05	8.2
DEC.	0.02	1.	0.18	12.2
TOTAL	7.38	20,822.	8.68	20,963

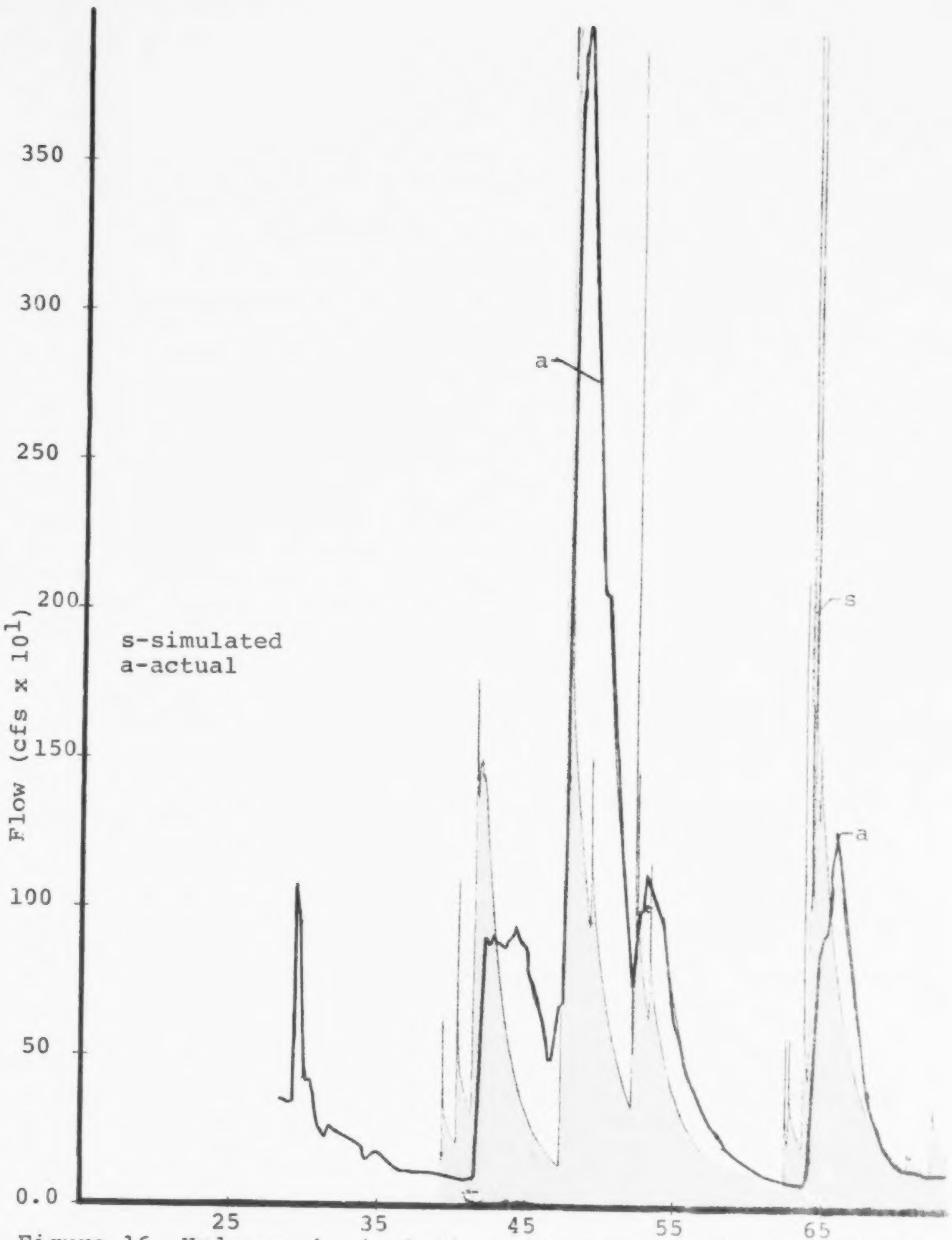

Figure 16. Hydrograph simulation without routing, February and March, 1976 (done as one basin at Melmore).

SECTION 8

HYDROLOGIC ROUTING SUB-ROUTINE

There is little question that the successful application of any hydrologic and chemical transport model to a watershed greater than a few square miles must include a sub-routine for routing the various sub-basin hydrographs through the network of channels to the measured station. For the purposes of this discussion, it is important to distinguish between the movement of fluid waves or hydrographs, and the movement of actual parcels of water and the suspended sediment particles associated with them. First, the NPS model simulation of flow will be routed as a fluid wave in an effort to replicate the observed hydrographs at the Melmore gage. Then, the same routing-routine will be applied to the NPS model simulation of suspended solids and sediment-associated phosphate, but at particle velocity. Conservation of mass will be maintained, with the calibrated volumes shown in Table 20 redistributed in time.

Using storm D (Runoff from March, 2-11) of 1976, as an example, development of the routing is presented as a three step process:

1. Time of travel (TT) from the subbasin mouths.
2. Time of travel + sub-basin time of concentration (Tc)
3. Time of travel + intrabasin routing (IBR).

Only the (TT +IBR) step is applied to the entire February - March 1976 period and the February - March - April 1977 period. All routing results are presented as hydrographs or chemographs and are compared directly with actual data for the period routed.

Almost all existing techniques for hydrologic routing have evolved through the need to predict the maximum stage and timing of flood conditions, a problem that necessarily is concerned with the movement of the maximum fluid wave, or flood crest through the main channel and the overbank flooding which results. The techniques used in routing analysis are generally considered to be either hydraulic, based on the equations of unsteady non-uniform flow in open channel and continuity (Chow, 1959) or hydrologic, based on the movement of observed hydrographs through the channel system. The method utilized is selected based on the data and computational resources available as well as the degree of detail required.

PRIOR HYDRAULIC ROUTING IN HONEY CREEK

A 1967 study by SCS in the upper Honey Creek involved the calibration of the TR-20 runoff model (Soil cover complex method) and routing of flood waves by the hydraulic "method of characteristics" (Massau, 1900; Lin, 1952) focused on very localized flood conditions, because parts of the main channel had been cleared and diked to protect contiguous farm fields. The primary concern was the maximum flood stage reached and its frequency of occurrence, so that structural modifications could be made to the channel and dike system. As part of this study, a great deal of detailed information was gathered on channel cross-sections, bridge structures, historical high water marks and other topographic features, as well as channel roughness or friction factors (Manning's "n"). Although the TR-20 study for Honey Creek never entered its second phase, some routing analysis was made for selected storms occurring in the upper watershed, with time of travel estimates to the juncture with Aichholtz Ditch. No actual rated stations were developed, but theoretical discharge velocity curves were calculated for selected cross-sections based on Manning's equation with estimated values of "n" and channel slope "S". The cross-sections for which these theoretical discharge velocity tables were estimated are shown in Fig. 17.

TIME OF TRAVEL FROM HONEY CREEK SUBBASIN TO MELMORE

The problem faced in the present study is to utilize the TR-20 study results, other available information and the NPS model output to simulate the actual hydrographs occurring at the Melmore gage during 1976 and 1977. Because no other detailed hydrographs were measured in the basin above Melmore during any of the recorded events, hydrologic methodologies for routing are of no value. Also, because the localized flooding is of no immediate concern in this analysis, a detailed procedure such as the one TR-20 model uses would be a case of overkill, considering all of the simplifing assumptions made in the NPS model itself and the input parameters utilized (uniform precipitation, Tiffin hourly records, infiltration rates, etc). After several efforts at more complex procedures, a simplistic routing methology was applied based on the time of travel (TT) of flood waves from individual sub-basins moving through the channel systems at the kinetic wave velocity (1.5 x fluid velocity).

Routing models that rely on kinematic wave assumptions have been successfully developed on large watersheds (Quick and Pipes, 1975), where a series of actual hydrograph records exist in a river network. In Honey Creek, of course, this is not the case at present, and so a complete hydrograph routing did not appear warranted. Rather, it was decided to move the flow in each

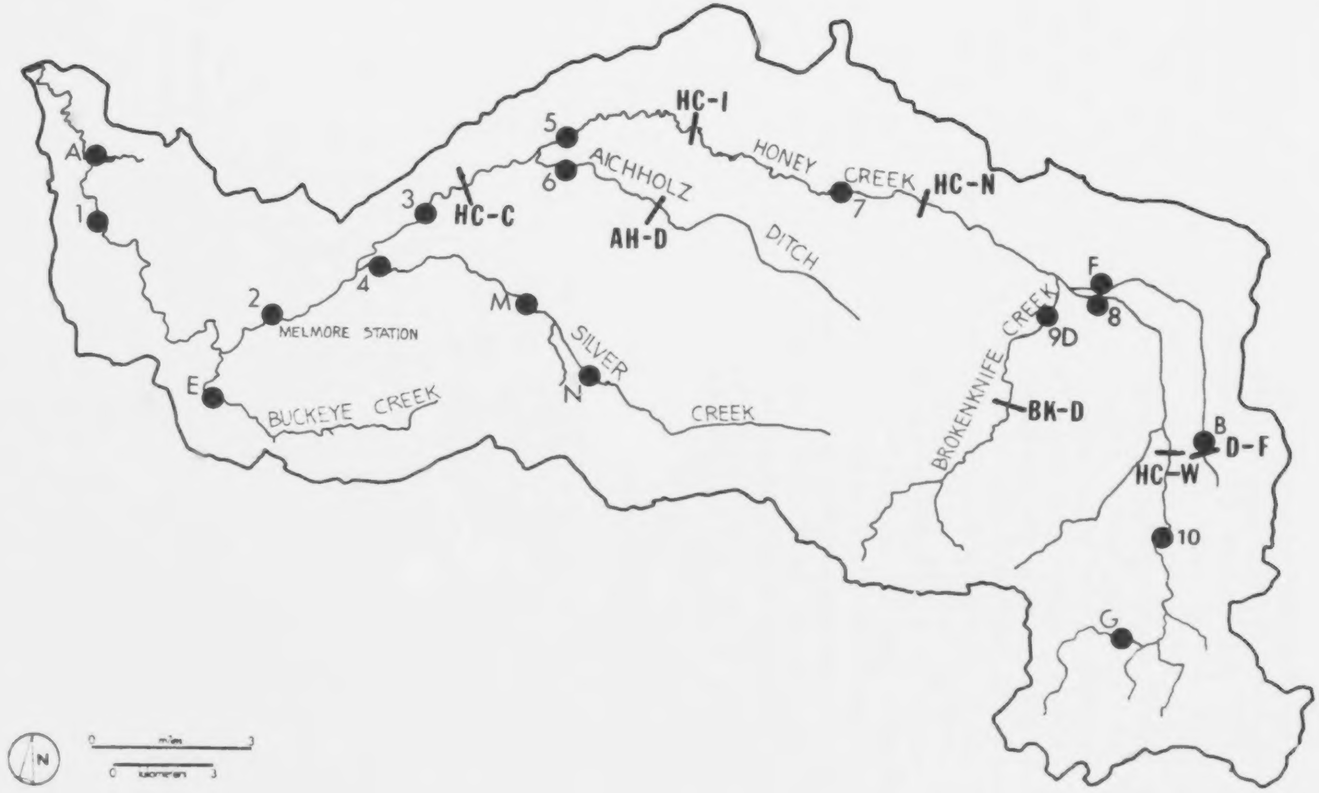
A
1
2
MELMORE STATION
3
HC-C
4
E
BUCKEYE CREEK
5
6
HC-I
AICHHOLZ
AH-D
DITCH
HONEY CREEK
7
HC-N
M
N
SILVER
CREEK
BROKENKNIFE CREEK
9D
BK-D
F
8
B
D-F
HC-W
10
G
N
0
miles
3
0
kilometers
3

Figure 17. Channel cross-sections used in routing.

simulation interval of the subbasin hydrograph at the velocity occurring at some fixed fraction of the simulated flow for that simulation interval. Ideally, the velocity occurring at the actual flow should be used but because actual flow is only available at Melmore during the calibration period, some other flow source must be selected to determine velocity. Use of simulated flow (Qsim) to determine velocity (V) would lead to an underestimation of travel time peak. In order to select a better stand-in for actual flow, the simulated peak flows (Run 33) for the February and March 1976 storms were compared to the actual peak flows, excluding the snow melt event.

For these settings of the model parameters, the ratio of actual to simulated maximum flow (Qmax.act./Qmax.sim.) clusters around 0.25. Therefore, to determine the velocity of flow during a simulation interval, Qsim is multiplied by the ratio and the resulting adjusted flow (adjusted Qsim) is converted to velocity in the QV table for that stream reach. The Qmax values were selected for comparison since they are quasi-independent of time and thus easily identified. Such a procedure to determine Q for conversion to V and time of travel is a good approximation only for peak simulation value. At low flows, use of the correction ratio will seriously underestimate actual flow velocity. However, there are two reasons why this shortcoming should not seriously affect the routing results. First, the velocity is fairly insensitive to flow in the lower flow ranges. Second, the relative amount of water possibly misrouted by this error is minor compared to the total flow of the storm peaks.

The movement of full hydrographs by kinematic wave in full models (such as the UBC model) assumes linearity in the flow-velocity relationship (Q-V), which is not true in Honey Creek channels. In fact, one of the key assumptions made in this present routing procedure is that during overbank flooding conditions, the flood wave celerity is a function of main channel velocity rather than the average velocity of the full section. Because only one flow is routed in this procedure, the actual QV table for the identified segment (Fig. 18) is used, avoiding the assumptions of linearity. It is also assumed that the NPS model is correctly calibrated if the simulated total flow for a given storm period is equal to the actual total flow, and only the timing of water parcels is incorrect.

The steps of the routing procedure that consider time of travel from subbasin mouths to Melmore are summarized:

1. Select storm period to be routed.
2. Run unit area (1 sq. mi.) NPS simulation for all subbasins (Fig. 18).
3. Identify stream segments through which each subbasin hydrograph must be routed.
4. Identify QV curve that applies to each stream segment.
5. Sum the drainage area above each segment.

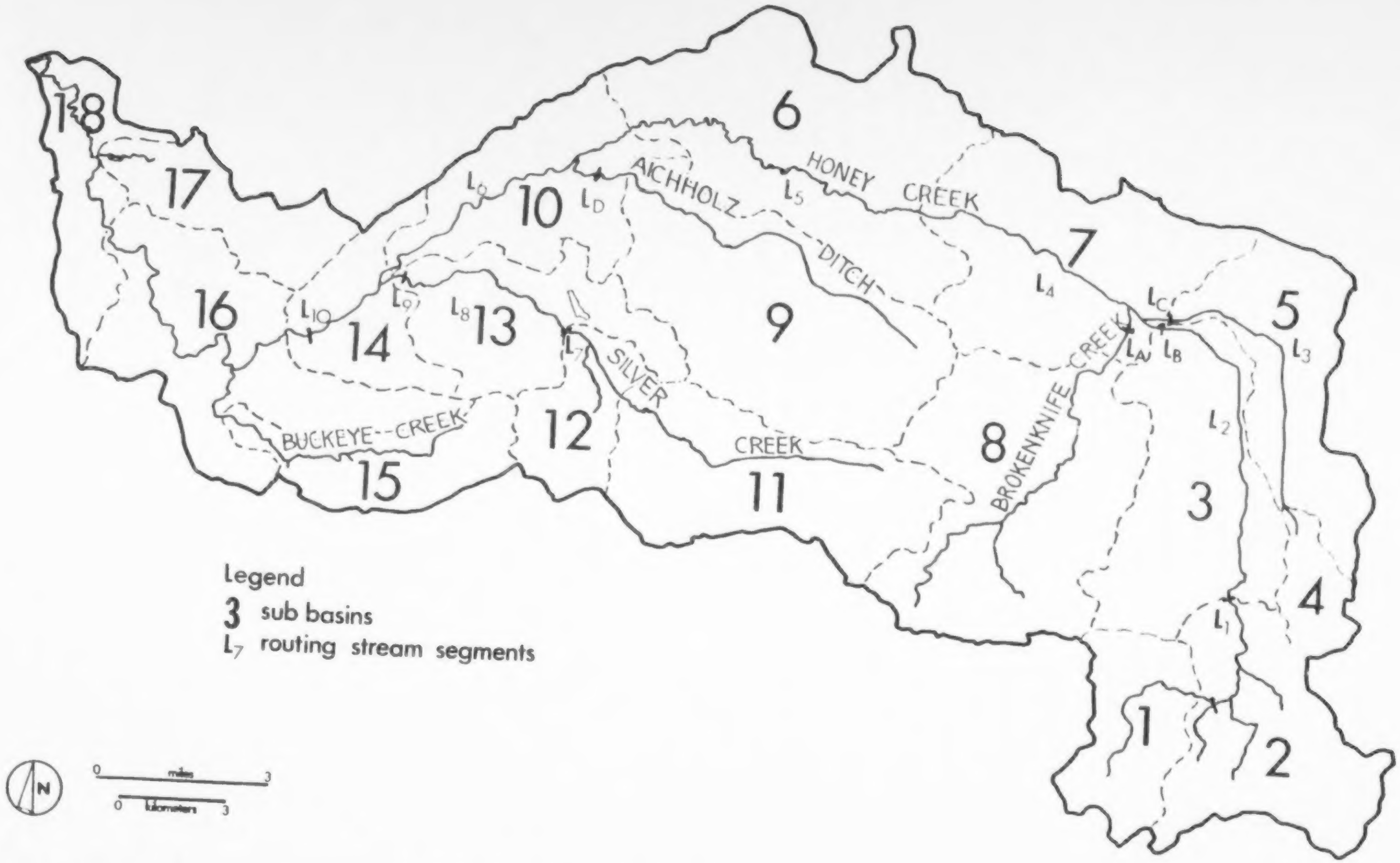
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
HONEY CREEK
AICHHOLZ DITCH
SILVER CREEK
BUCKEYE CREEK
BROKENKNIFE CREEK
L_1
L_2
L_3
L_4
L_5
L_6
L_7
L_8
L_9
L_{10}
L_A
L_B
L_C
L_D
Legend
3 sub basins
L_7 routing stream segments
N
0 miles 3
0 kilometers 3

Figure 18. Channel segments and sub-basins used in routing.

6. Multiply unit Qsim by adjustment ratio and by drainage area above each segment to get adjusted Qsim.
7. Calculate V for each segment using adjusted Qsim and the appropriate Q-V curve.
8. Calculate time of travel (TT) in hours for each segment (TT = 0.67L(ft)/V (3600)).
9. Sum times of travel for all streams segments through which flow from each subbasin is routed.
10. Multiply unit area simulated hydrograph of each subbasin by its area.
11. Integrate subbasin simulated hydrographs at Melmore, each displaced by time of travel determined in step 9.

Preparation of the Calibrated NPS Model Output for Routing--

As documented above, the NPS model was calibrated for the area of Honey Creek watershed above Melmore with NLAND (land uses) set at five: row crops, small grains, woodlot, water/wetland, and urban. The opportunity to route the results from the calibrated model, however, allowed a fuller use of the available land use data. It was desirable, though, to reduce the number of individual NPS model simulations required for the 14 subbasins to be routed. In order to achieve this, the NPS model was run five times, once each for the five "pure" land uses types listed above with NLAND = 1 and ARFRAC = 1.0. In each case, a unit area of 1 square mile was applied (AREA - 640). The simulated flow from each of the 14 subbasins was then reconstructed by applying the percentage of each land use in a subbasin to the simulated flow from the unit area of the corresponding land use type and summing over all land use types present in the subbasin.

The result of the above calculation represents the simulated flow from 1 square mile of the subbasin. This unit area flow was then multiplied by the area of the subbasin to obtain its full simulated flow. This calculation was performed and the resulting flow was routed for every 15 minute simulation interval occurring in the period selected for routing.

In Table 21 are shown the percentages of the five land uses in each of the 14 subbasins that were used to obtain the input flows to the routing routine.

RESULTS OF ROUTING USING SUBBASIN TIME OF TRAVEL (TT)

A schematic representation of the routing achieved by application of this procedure is shown in Fig. 19 for five consecutive simulation intervals, all with the same time of travel of 10 hours. Routing of storm D (March 2-11, 1976)

Table 21. LAND USE COMPOSITION OF SUBBASINS IN HONEY CREEK ABOVE MELMORE

Subbasin Number	Row Crop	Small Grains[a]	Woodlot	Water/ Wetland	Urban
1	.592	.274	.085	.007	.042
2	.480	.365	.097	.007	.051
3	.490	.379	.073	.011	.047
4	.457	.402	.109	.013	.014
5	.380	.294	.064	.242	.020
6	.512	.311	.127	.009	.041
7	.529	.268	.117	.029	.057
8	.515	.306	.095	.016	.063
9	.533	.304	.089	.013	.061
10	.492	.309	.129	.014	.058
11	.592	.271	.090	.015	.032
12	.428	.343	.180	.035	.014
13	.465	.305	.152	.041	.037
14	.522	.325	.095	.012	.046

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a. Includes small areas of 'other agriculture'

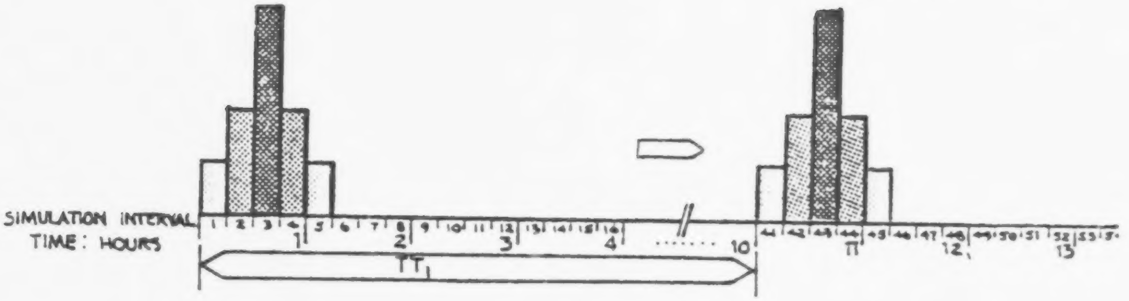

Figure 19. Schematic representation of time of travel routing. A simplified hydrograph occurring in 5 simulation intervals is shown by time of travel. In this example TT is constant.

by the above 11 step procedure is shown in Fig. 20. This routed result has reduced the sudden intense response and the prematurity of the unrouted simulation, and the time of travel displacement has significantly improved the fit to the actual hydrograph. However, the simulated hydrograph is highly fluctuating and still precedes the actual.

The times of travel used in this preliminary routing example were calculated for each of the stream segments shown in Fig. 18. Interpolation and extrapolation algorithms were used to determine V from possible intermediate and out-of-range adjusted Qsim values from the respective Q- V curves. The full section velocities during overbank flooding conditions were not used, because it is assumed that both the fluid wave motion and the suspended solids velocity are best represented by the main channel velocity. It is recognized that this is not strictly the case, but a reasonable approximation that will lead to a slight overestimation of waves and particle velocity and a subsequent underestimation of travel time during high flow periods. Time of travel values developed in this routing example are used in the next example with the addition of intrabasin time of concentration.

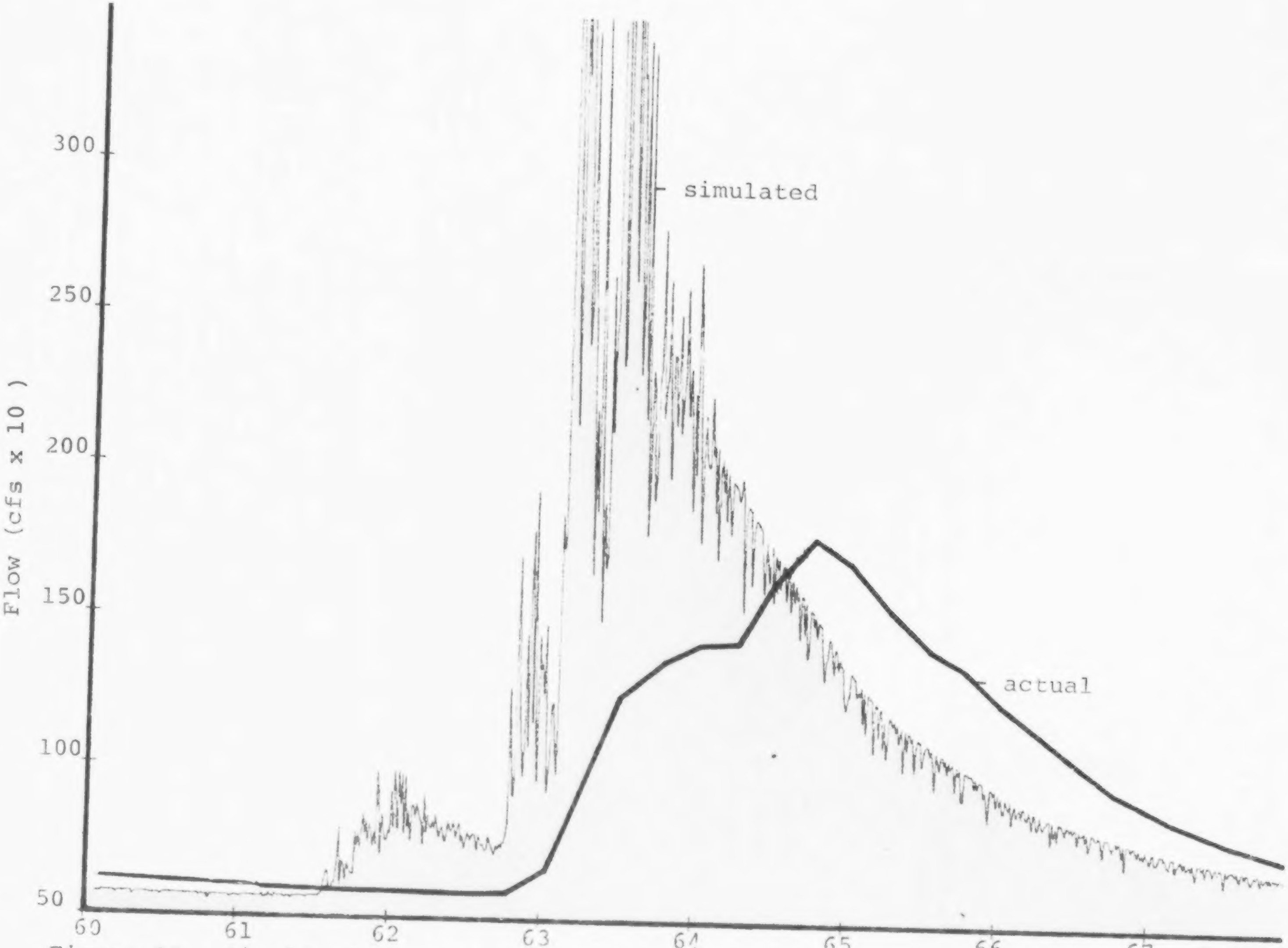

Figure 20. Simulated Storm D (1976) routed by time of travel displacement. Each simulation interval routed independently.

TIME OF CONCENTRATION (Tc) WITHIN SUBBASINS OF HONEY CREEK PLUS TIME OF TRAVEL

Consideration was given to various methods for estimating the time required for each of the simulated hydrographs to actually develop in the 14 sub-basins, ranging in size from 3.38 sq. mi. (sub-basin 4) to 20.49 sq. mi. (sub-basin 8). Evaluation of the NPS model LANDS algorithms indicated that adjustment of the recession parameters (IRC, KK24) and INTER were inadequate to simulate the time delay of interflow experienced in a tile underdrained basin such as Honey Creek. Various schemes were considered which would utilize the Honey Creek cellular data base LRIS) and drainage network geometry, but this approach was deferred for later research.

Simplistic methods that estimate the time of concentration as a function of basin geometry (length of basin, slope or elevation differential) and surface condition (surface roughness coefficient) were compared with the Tc estimated in the SCS TR-20 model calibration in 1968 for Upper Honey Creek. These included two forms of the Kirpich equation (1940) and the general equation for overland flow (Chow, 1959). Although none of these can adequately describe the complex elements of a hydrograph in a sub-basin such as Broken Knife Creek or Achholtz Ditch, they approximate the delay in runoff within sub-basins. The times of concentration calculated for the TR-20 model application to the upper Honey Creek subbasins were selected for use in the routing routine. Values of Tc for subbasins 10-14 were estimated based on similarity with the subbasins for which TR-20 times were available. The time displacement of the simulated flow by applying both TT and Tc is shown schematically in Fig. 21.

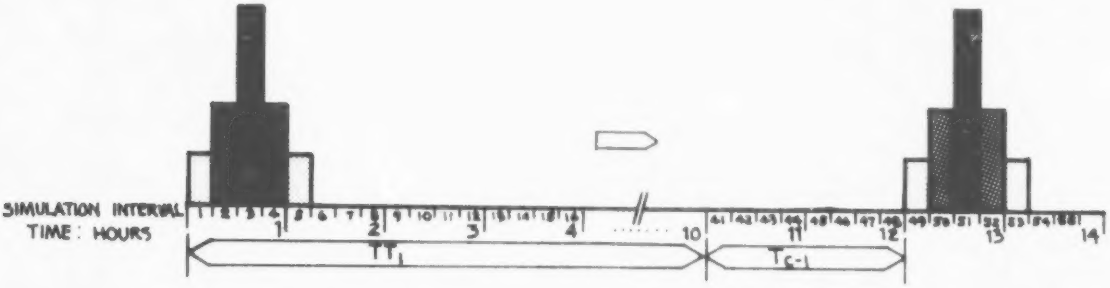

Figure 21. A schematic representation of time of travel plus time of concentration routing for 5 consecutive simulation intervals.

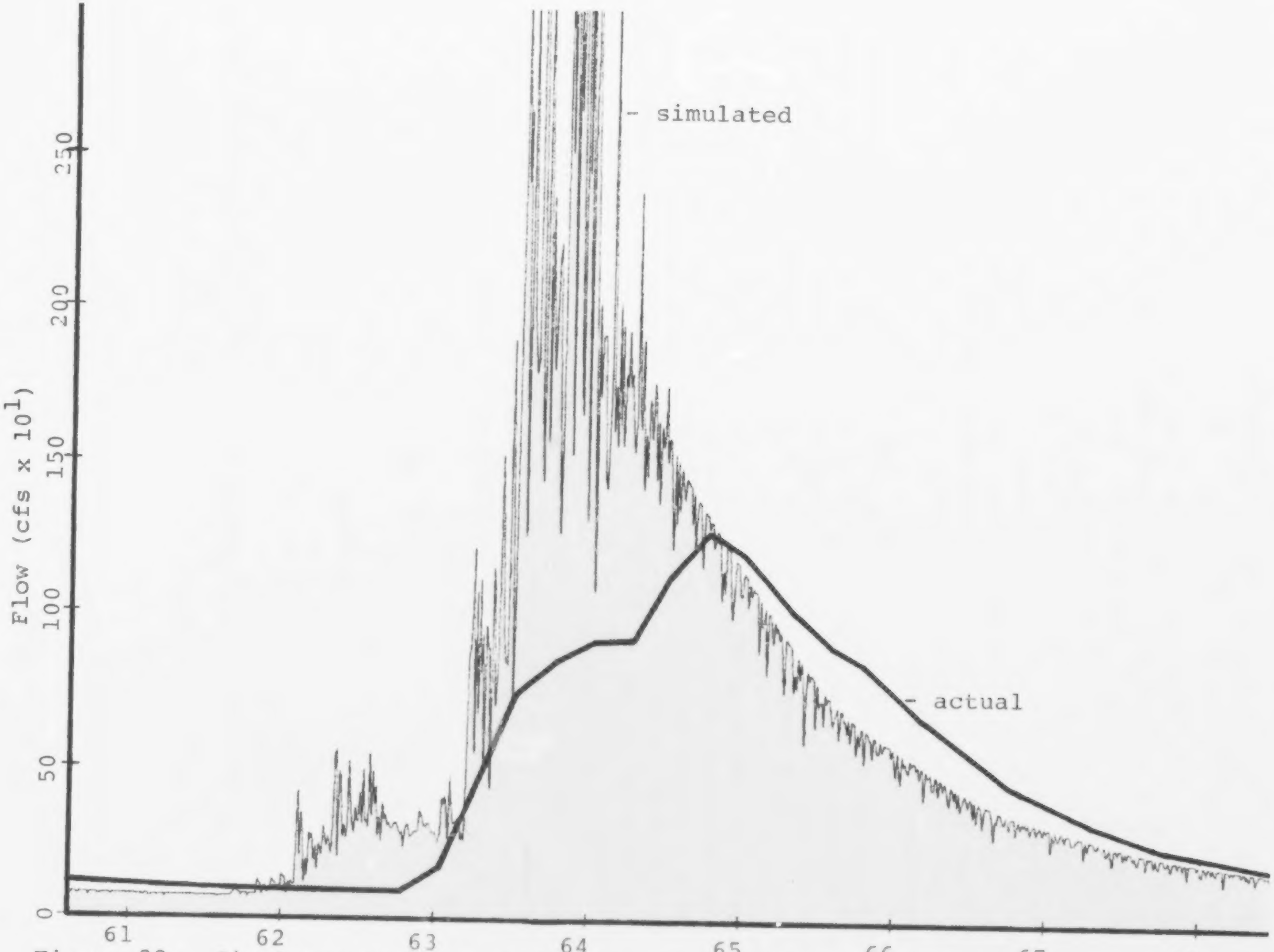

Figure 22. Simulated Storm D (1976) routed by time of travel plus time of concentration displacement. Each simulation routed independently.

Application of the time of travel procedure as outlined in the previous section plus the estimated time of concentration to the NPS simulation of storm D produced the hydrograph shown in Fig. 22. It can be seen that the routed hydrograph is shifted slightly ahead of the actual hydrograph and that it still fluctuates significantly.

INTRABASIN ROUTING PLUS TIME OF TRAVEL

As mentioned above, the TT + Tc routing procedure yielded a fluctuating hydrograph appearing slightly earlier than the actual hydrograph. Routing the NPS model output in this way shifts the entire volume of water in a simulation interval from one simulation interval to a single future one. The simulated hydrographs from the 14 subbasins arrive at Melmore over a number of simulation intervals determined by the TT + Tc displacement. The variable time displacement tends to spread the simulated hydrograph over a period as long as that of the real hydrograph. The spikey nature of the unrouted simulated hydrograph, however, is sustained in the routed hydrograph as a result of assigning all the volume of water in a simulation interval to just one other in the routed hydrograph (see Fig. 22). It was desirable to improve the routing routine in a way that would reduce the spikey nature of the hydrograph, would bring better agreement between the routed and real hydrographs, and would conform more closely to reality than the TT plus Tc concept. To these ends, a simplified device was applied that first displaces the flow from each simulation interval by its TT (as above) then divides that flow equally among all the simulation intervals in Tc for that subbasin. Routing flow from one simulation interval by such intrabasin routing (IBR) is shown schematically in Fig. 23.

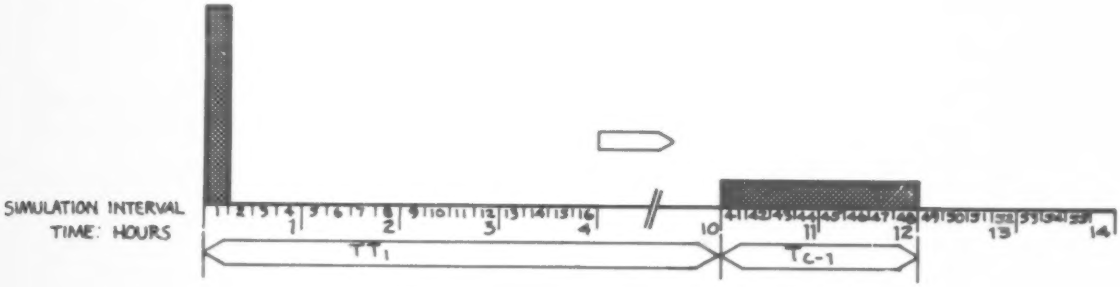

Figure 23. Schematic representation of time of travel plus intrabasin routing. Discharge from one simulation interval is displaced TT , then divided equally among all simulation intervals in Tc.

Physically interpreted, this routing modification means that flow from one simulation interval appears as stream flow in all parts of the subbasin simultaneously but that these parts take different lengths of time to deliver their flow to the subbasin mouth, the longest taking the interval Tc to appear. The Tc routing assumes that the flow from each simulation interval originated from the furthest point in the subbasin and none from intervening points. The result obtained when intrabasin routing is applied to a five simulation interval hydrograph is shown schematically in Fig. 24. As can be seen by comparison of Fig. 24 with 21, the routed hydrograph appears earlier and is considerably reduced in amplitude by applying intrabasin routing.

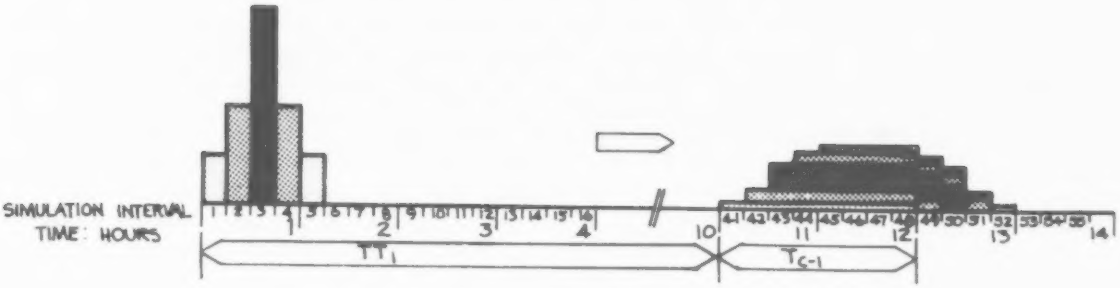
SIMULATION INTERVAL
TIME: HOURS
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
41 42 43 44 45 46 47 48 49 50 51 52 53 54 55
1 2 3 4 10 11 12 13 14
TT_1
T_{C-1}

Figure 24. Schematic representation of time of travel plus intrabasin routing II. Discharge is from 5 simulation intervals which are each displaced TT, then divided equally among all simulation intervals. The various textures indicate disposition of discharge from each simulation interval.

When IBR and TT routing procedures are applied to storm D, the result shown in Fig. 25 is obtained. The spikiness of the TT (Fig. 20) and TT + Tc (Fig. 22) hydrographs has been eliminated. The TT + IBR hydrograph, however, appears approximately one day earlier than the actual hydrograph. The cause of this displacement could be anyone or combination of the following

1. Estimation of TT is too low.
2. Estimation of Tc is too low.
3. A major component of peak flow, such as contribution from tile drains, is not modeled.
4. Error in precipitation record.

TT-IBR Routing for storms in early 1976

The TT-IBR routing procedure as illustrated for storm D, was next applied to the entire February-March 1976 period (Julian day 32-60). The results of the routing are shown in Fig. 26. It is seen that the calibrated NPS model input, with TT-IBR routing, produces storm hydrographs that appear earlier with higher maximum flows than actually occurs. The earliest simulated peak in Fig. 26, is actually not in response to rainfall but is caused by the high initial setting of UZS and LZS. Note also that between Julian days 70 and 90, the model as calibrated shows three hydrologic responses to rainfall that were not actually recorded at Melmore. This could also be caused by deficiencies in the rainfall record.

CHEMOGRAPH ROUTING

Attention next turned to the question of routing of suspended sediments, a different problem from the fluid wave movement simulated in the preceding sections. As discussed previously, chemographs almost invariably precede hydrograph peaks, and frequently diminish in magnitude with subsequent increases in flow. This phenomena is well illustrated by 1976 storms, as shown in the expanded scale Fig. 27. The D hydrograph has two distinct peaks, obviously one runoff occurred shortly after the first had peaked. The chemograph, however, shows three distinct peaks and possibly a fourth, all occurring out of synchronization with the hydrograph, except for the second. The hourly rainfall record is shown in Fig. 13, with three major and one minor bursts, possible corresponding with the chemograph peaks.

The NPS model in its present form produces chemograph response preceding the hydrograph peak by exhausting the fines pool with the first flush of overland runoff simulated. If the available pool of sediment is quite large, the simulated overland flow input carries with it the suspended sediment in direct proportion, producing a chemical peak identical with the flow peak. This limitation is identifiable in prior NPS model calibration effects, even on the smallest of watersheds, such as P2 water-

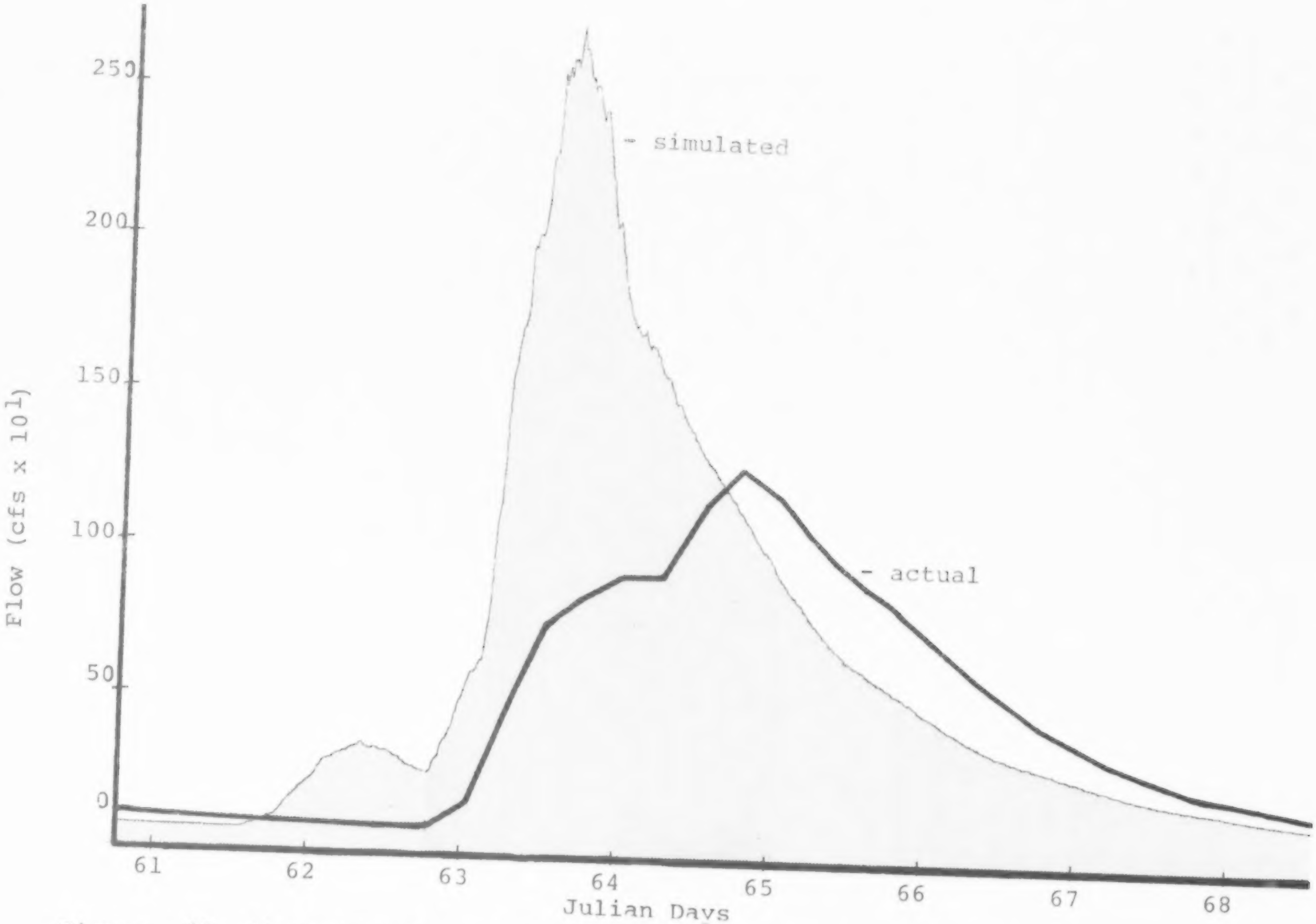

Figure 25 Simulated Storm "D" (1976) routed by time of travel plus intrabasin routing.

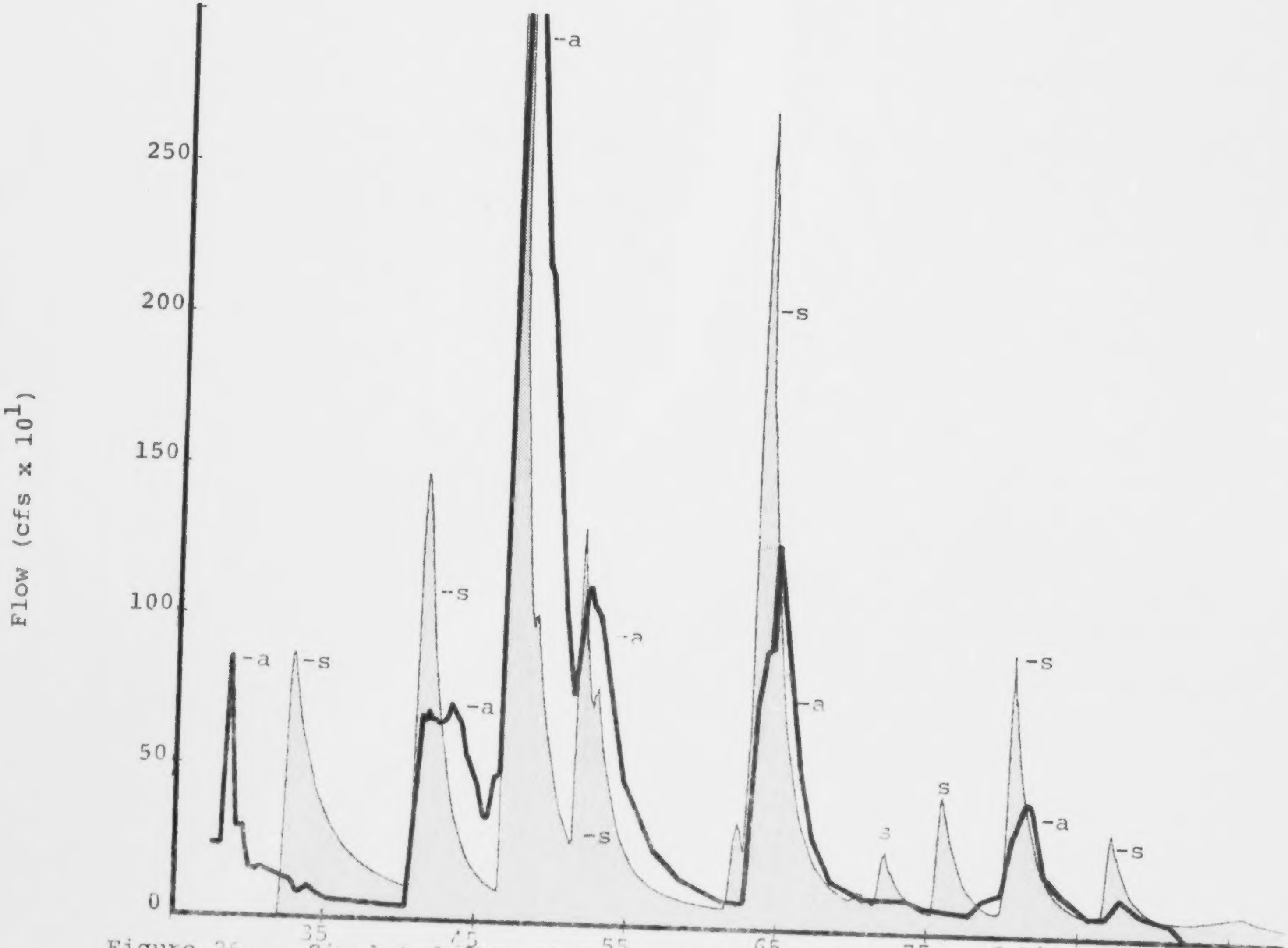

Figure 26. Simulated flow of February-March 1976 (Julian day 32-60) routed by time of travel plus intrabasin routing.

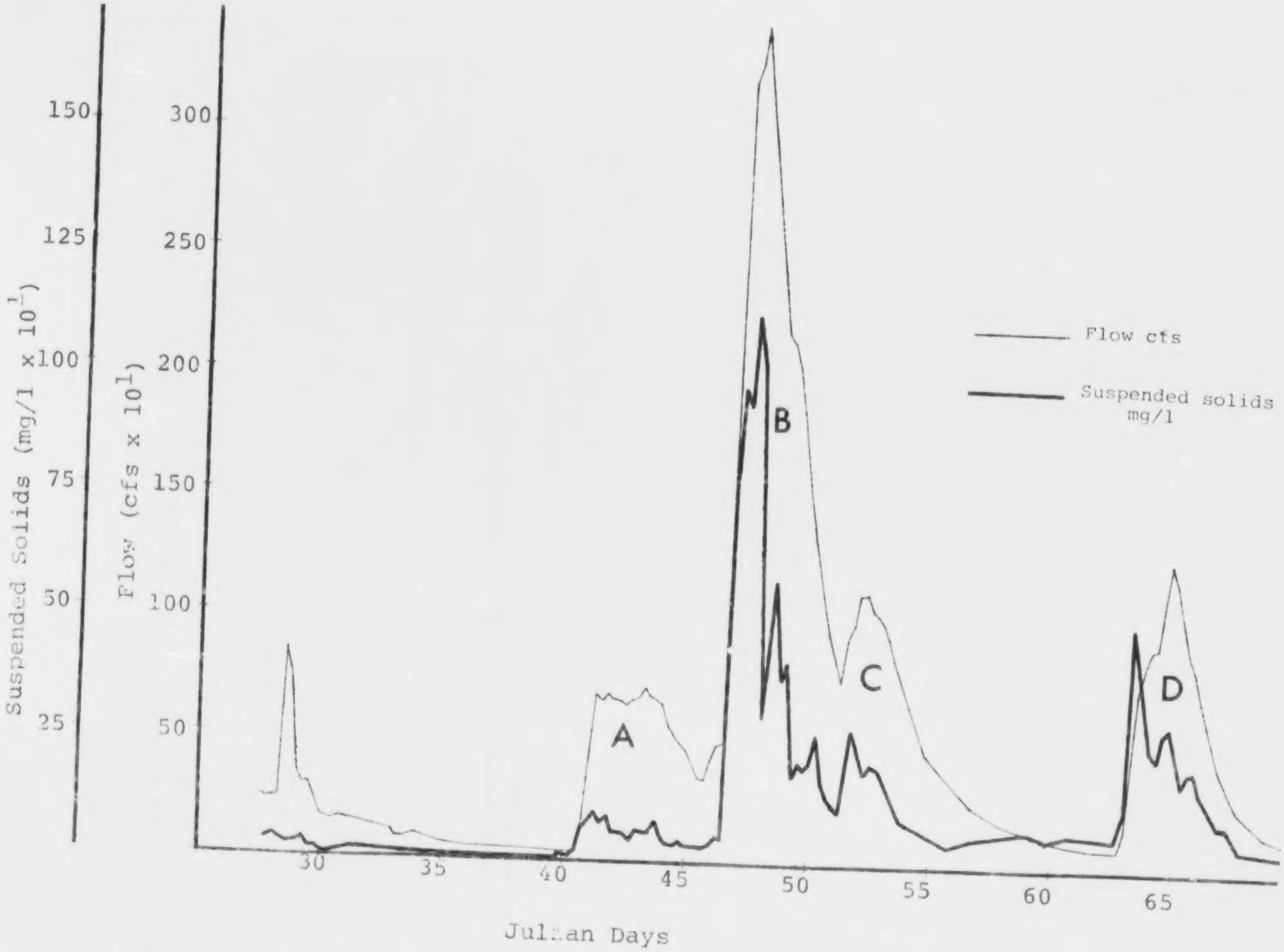

Figure 27. Chemograph precedence of hydrograph, 1976.

shed, Watkinville, GA., and Third Fork Creek, Durham, NC (EPA, 1977). This precedence of hydrograph by chemograph has been observed almost universally in all such studies of stream transport (Cahill, 1974; Baker, 1973). The problem faced in this calibration of the NPS model to a large agricultural watershed is that the fines pool is seldom exhausted, unlike an impervious basin. Variable response areas can be approximated with the ARM model algorithms which divide a watershed into zones which vary the cumulative frequency function, but that flexibility is not available in NPS.

Given the limitation in the NPS model, the chemograph calibration will consider the same two time displacements of indiviual chemographs, TT + IBR, as were applied to sub-basin hydrographs, with one exception; the fluid velocity in channel reaches will be used rather than the wave velocity. The result of this routed chemograph are shown in Fig. 28 for storm D. Because the hydrographs were out of synchronization, the chemograph, routed at the slower velocities actually shows a better correlation. The full February and March chemographs simulation is shown in Fig. 29, with the simulated runoff tending to occur in bursts with extreme peaks, rather than the smoother curves which actually occur. The overall mass transport simulation for the routed model is good for the various storms in terms of total load, but the long, drawnout transport cannot be simulated, at present, with the NPS model.

One major shortcoming of the routing scheme used is that since this NPS program lacks algorithms describing in-channel flow, several very important phenomena are neglected, including channel storage, sediment scour or deposition and dispersion. The use of such algorithms, of course, will require very extensive and detailed data on channel geometry, bed condition and sediment particle size distribution which are seldom available except for small catchment studies.

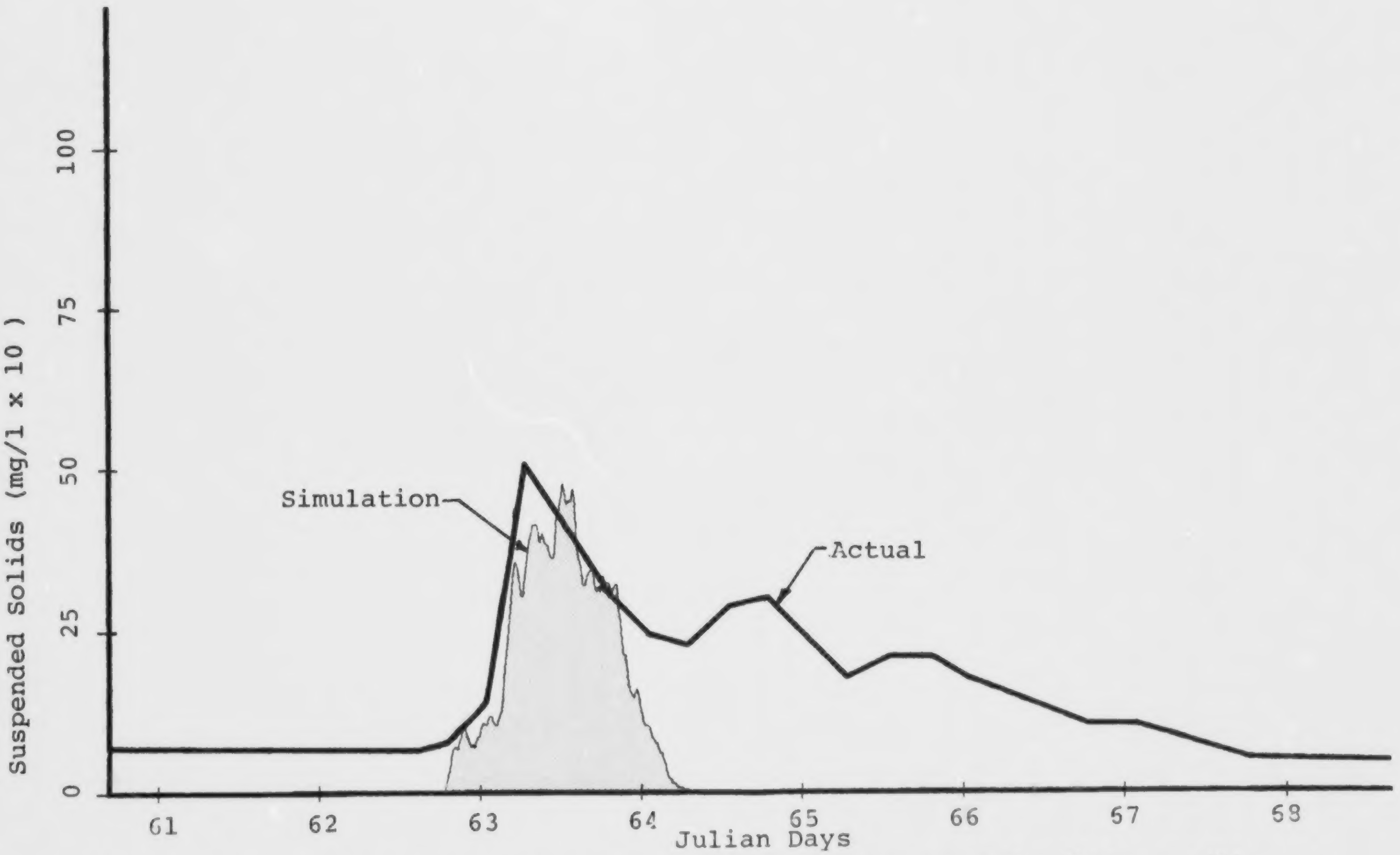

Figure 28 Routed Chemograph: storm "D", 1976. (suspended solids, mg/l)

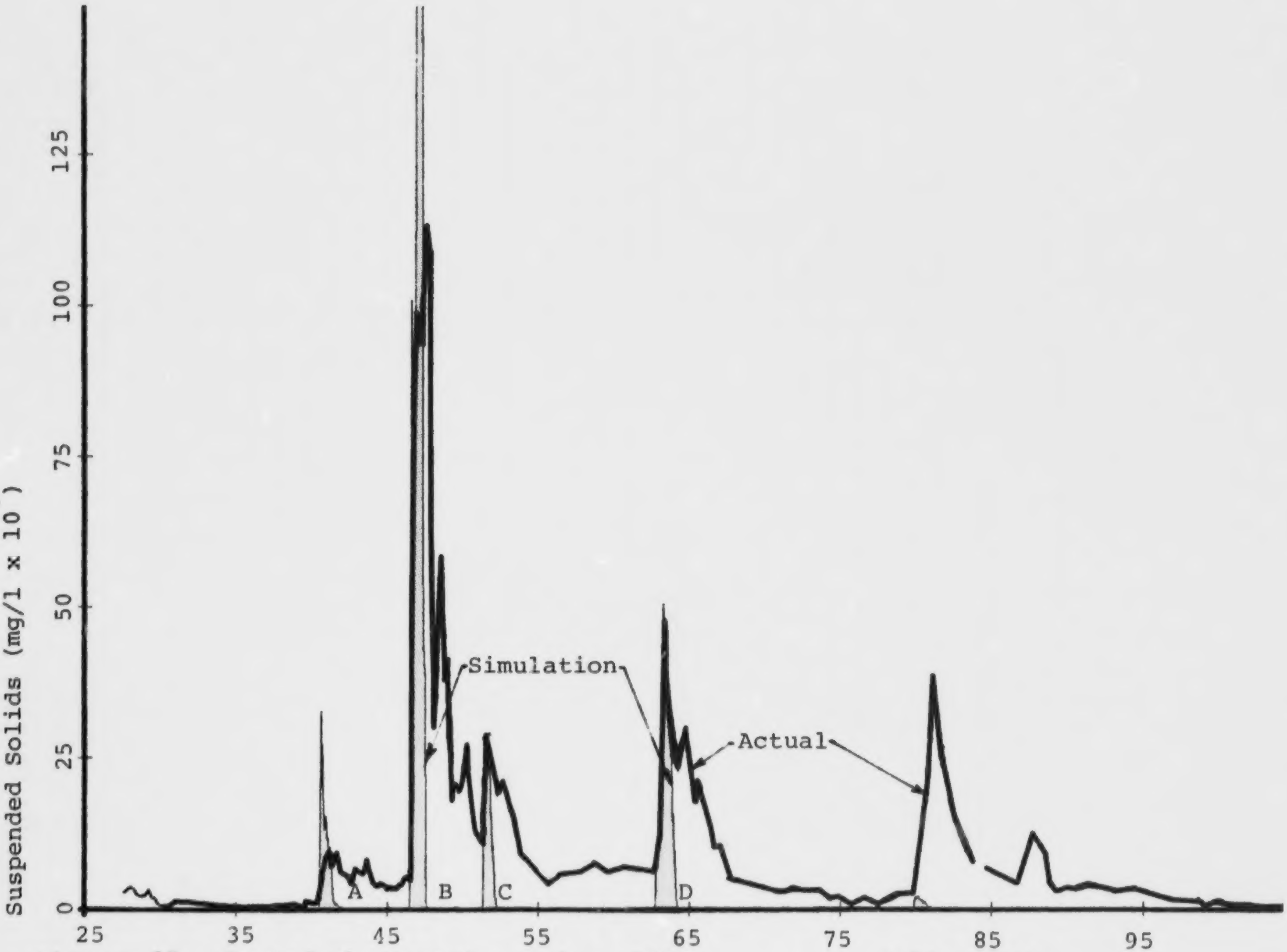

Figure 29. Routed chemograph: spring, 1976.

SECTION 9

MODEL VERIFICATION

1977-RECORD OF HYDROLOGIC EVENTS

As previously mentioned, calendar year 1977 had a very different distribution of hydrologic event response and chemical runoff from 1976, although the rainfall distribution was not all that different with the exception of a very wet March. The late February thaw period still produced the highest runoff values for the first nine months of the year, but at a peak less than a third of the 1976 value. Corresponding concentrations of suspended solids and total particulate phosphate were also appreciably lower (Table 22). Storm "B" was particularly curious, producing a runoff of 1.3 inches with a recorded precipitation of 0.05 to 0.10 inches, obviously a situation where ground thaw contributed significantly to runoff. The actual snowmelt had occurred a week earlier, but apparently been stored in the upper soil layer and not released until ground thaw, shown in Fig. 30. The pollutant concentrations were quite high, suggesting a significant buildup of sediment from the winter period. March was a particularly wet month with 4½ inches of rainfall, but runoff volume and pollutant concentrations were lesser in magnitude than in 1976. This heavier rainfall in the early spring allowed storms through April and May to produce significant runoff, whereas in 1976 this was not the case.

The runoff period from February 22 through March warrants detailed consideration. As shown in Fig. 30, the 12 inches of snow on the ground as of February 8 (equal to 1.61 inches rain) melted to less than 3 inches by February 12, with the ground thawing just enough to hold this melt but not sufficiently to allow percolation to the tiles. With temperatures dropping well below freezing from February 15 to 21, the major portion of this moisture remained trapped, at or near the soil surface. The warming period which began on February 22 freed this soil ice and began heavy runoff, much of it being overland flow. The small precipitation of the 24th (0.1 in.) occurred on near saturated conditions, thus the dramatic suspended solids peak following rainfall by about seven hours. The major rainfall for the period occurred late on February 26 and early on February 27 (0.9 inches at Tiffin, only 0.3 inches at Plymouth and Bucyrus), but produced only a slight peak on the recession hydrograph and almost imperceptable chemical increases.

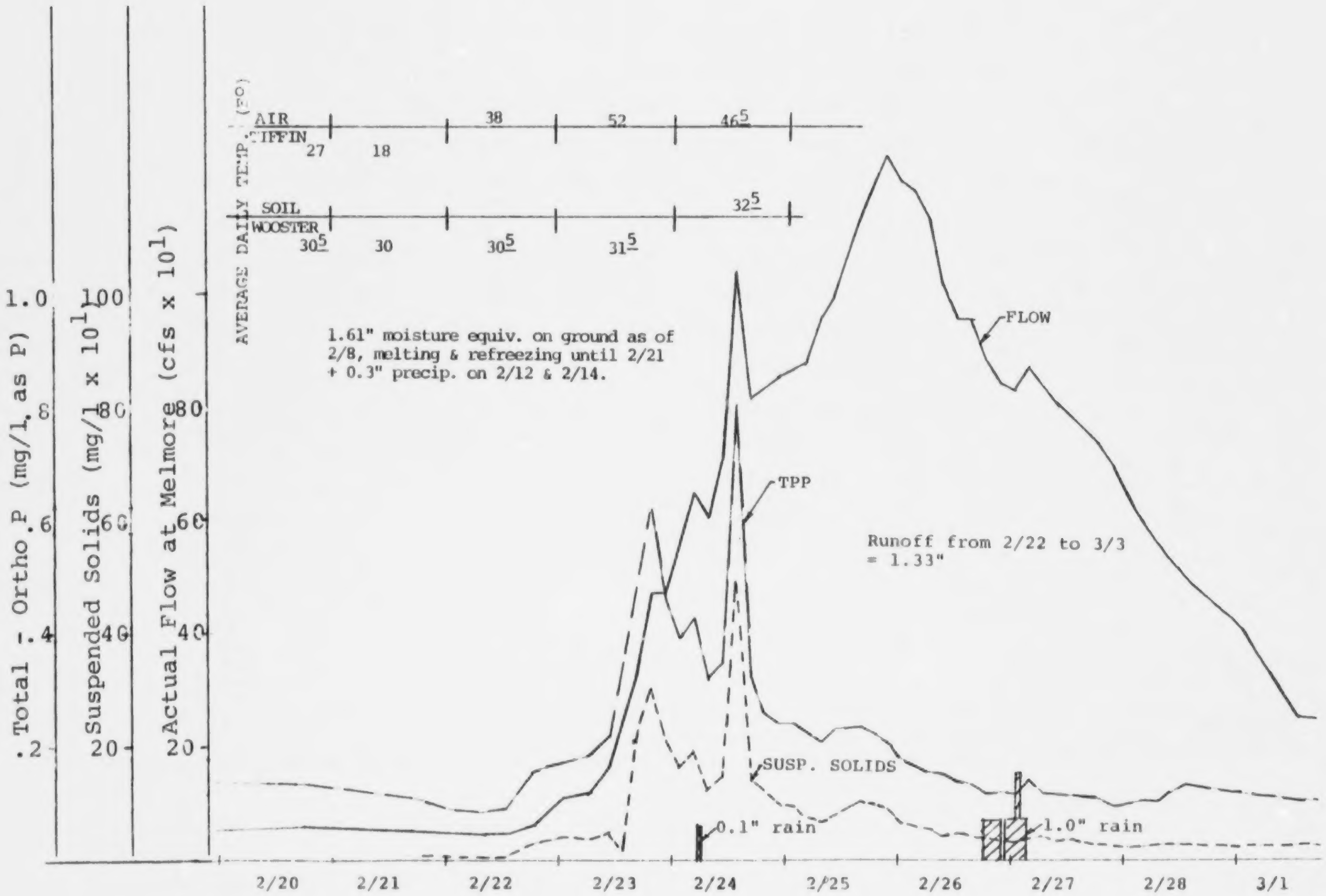

Figure 30. Late winter runoff period, February, 1977.

Table 22. MAJOR STORM EVENTS, HONEY CREEK BASIN, 1977

(Melmore Gage Record)

Storm No.	Julian Day	Runoff Date(s)	No. of Hyd. Pks.	Q Max. (cfs)	TP Max. (mg/l)	SS Max. (mg/l)	Rainfall (in./day) Dates	Tiffin	Plymouth	Bucy.	Period Between Major St. No. of days	Total Rain (Tiffin)
											From 1/1 to 2/5=16.1 in. snowfall	no melt until 2/9
											43	
77 A	40	2/13-2/16	1	34	.68	20	2/13-2/15	0.23	-	0.35		
77 B	53	2/22-2/24	1	1043	.93	499	2/21-2/24	.05	.05	.08	5	0
77 C	55	2/24-3/03	1	1245	.36	105	2/24-2/27	1.04	0.41	0.39	0	0
77 D	63	3/04-3/09	1	415	.23	41	3/4-3/5	0.61	0.28	0.48	4	0
77 E	72	3/13-3/16	1	214	.16	47	3/12-3/14	0.65	0.35	0.80	6	0
77 F	77	3/18-3/22	1	890	.37	169	3/18-3/21	1.66	1.66	1.42	3	0
77 G	81	3/22-3/28	1	812	.33	70	3/22-3/23	0.83	0.72	0.78	0	0
77 H	88	3/28-4/1	1	517	.27	90	3/28-3/29	1.04	0.91	0.72	4	0
77 I	92	4/2-4/8	2	898 894	.61	82	4/2-4/6	1.22	2.03	1.89	3	0
77 J	112	4/22-5/01	2	336 257	.22	69	4/21-4/26	1.94	1.79	1.89	14	.08
77 K	123	5/3-5/09	2	627 644	.39	142	5/2-5/6	2.02	1.17	1.27	6	0.32
77 L	182	7/1-7/4	1	281	.98	1004	7/1	1.11	1.43	0.23	55	2.29
77 M	185	7/4-7/7	1	651	1.43	1626	7/4-7/5	0.25	0.97	1.03	2	0
77 N	188 (Some runoff)	7/7-7/10	2	318	0.73	418	7/8	0.70	0.73	0.12	2	0
77 O	(No runoff)						8/5-8/8	1.78	1.63	2.09	27	1.07
77 P							8/9-8/12	2.55	2.05	1.21	0	0
											8	0(0.91 @ Plym.)

The storms that followed in March, April and early May, some eight events in all (Fig. 31), conform to the classic pattern of chemograph preceding hydrograph by several hours, with the particulate phosphorus tracking the suspended solids. The most interesting aspect of these 1977 spring data is the fact that storms of the same general magnitude and duration as 1976 spring storms did produce significant runoff and pollutants, whereas in 1976 the April and May storms did not. The contrast between the two spring periods is striking and appears to be almost entirely a function of soil moisture storage.

MODEL VERIFICATION

In spite of the significant differences between 1976 and 1977 in terms of both hydrologic response and pollutant production in Honey Creek, it was decided to run the 1977 data using the final LANDS and QUAL input parameters for Run 333, with LZS, UZS, and SGW set as of December 31, 1976. The comparison of actual and simulated monthly values for flow and suspended solids mass transport is shown in Table 23. The table indicates that there are several major problems with the verification and they are apparently very different in nature.

First, the delayed snowmelt period of late February could not initially be predicted, because the rule used in accounting for snowmelt as runoff was to proportion it to the reduction of snow-on-ground measurement, resulting in simulated runoff almost two weeks too early. Obviously, the ground thaw must be considered in estimating the full snowmelt effect, but without solar radiation data such observation is hindsight. Realizing this, the snow-melt runoff was moved from the 8th to the 22nd, resulting in the simulation as shown. Even with the snow melt considered properly, the precipitation record and the stream flow record are incompatible, with two distinct chemograph peaks on the rising stage of February 23 and 24. The rainfall record only coincides with the second peak, and the major rainfall of late on the 26th and early on the 27th appears to have no relation to the hydrograph peak. It would appear that the problems of inconsistency with this event are poor rainfall data and improper snow melt input. From the model point of view, the simulation of even the precipitation of the 26th failed to produce any significant sediment production.

The hydrograph simulation is good for the February, March and April period, as shown in Fig. 32. With the exception of the snow melt event, all storms are simulated well, with the peaks still occurring too rapidly. The sediment simulation is not too good, however, with the model showing a marked lack of overland flow.

The largest single problem with the 1977 data used in model varification occurs in the period of early July. During the 4th

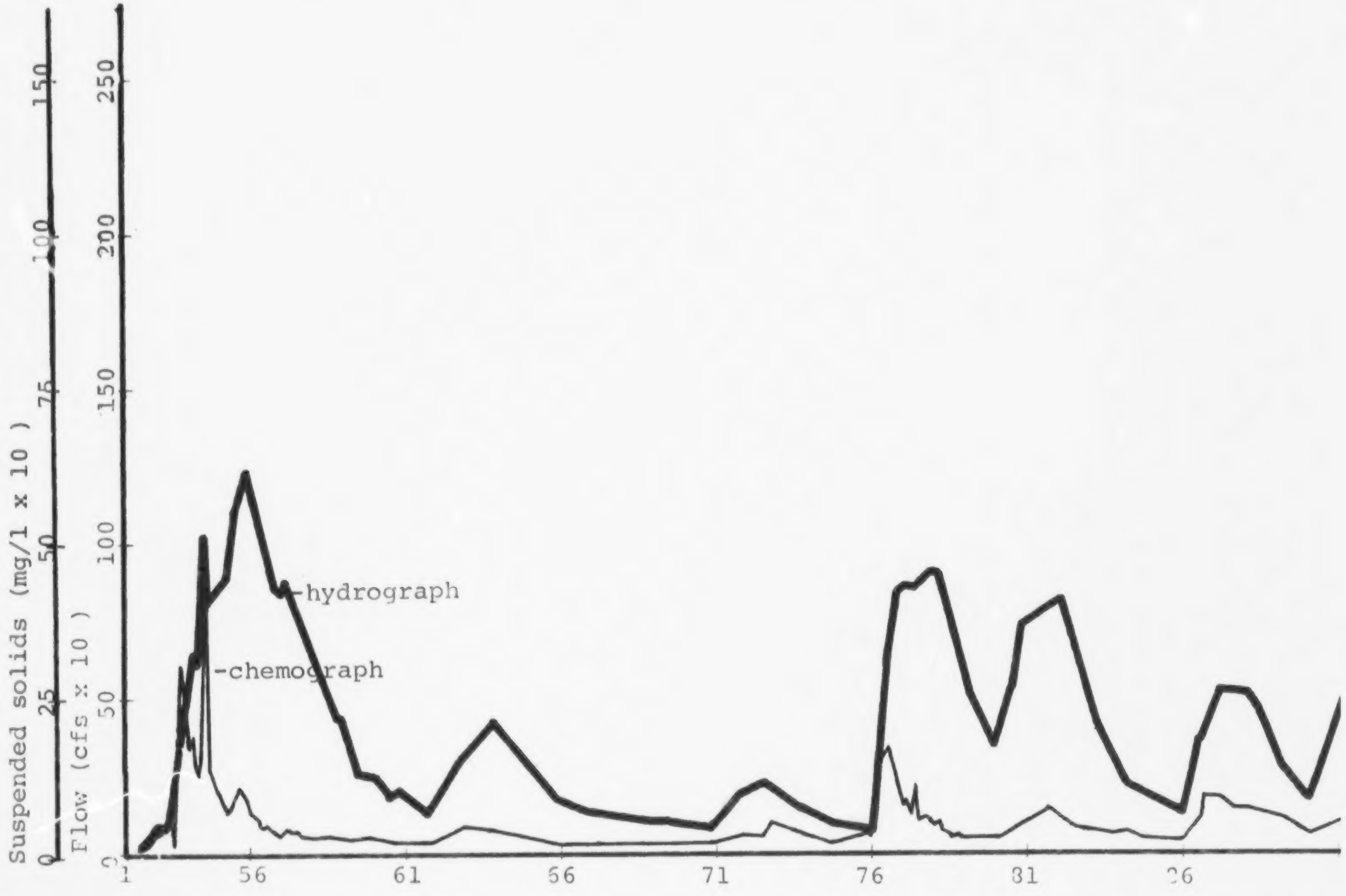

Figure 31. Actual hydrograph and suspended solids chemograph, 1977.

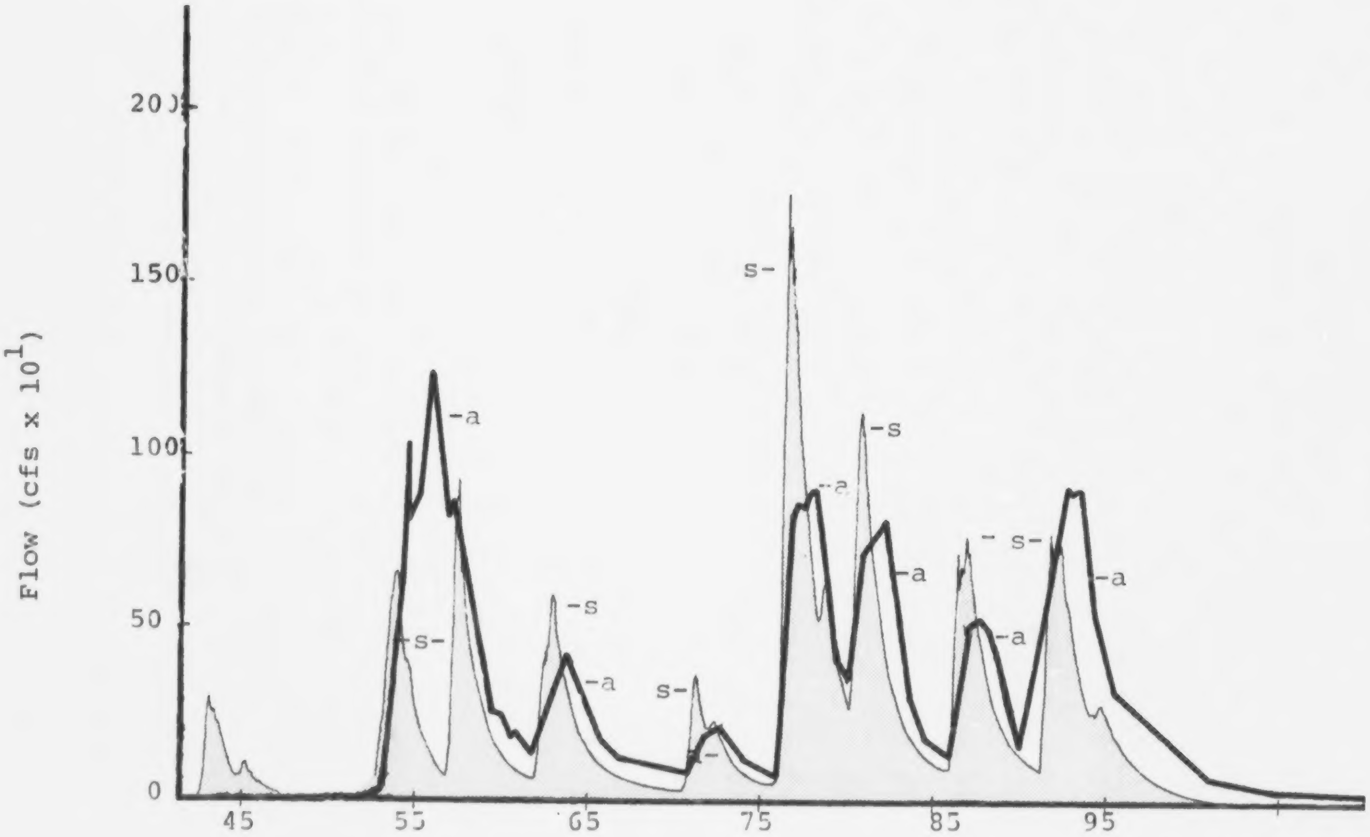

Figure 32. Simulated flow of February 1 to April 20, 1977 (Julian day 32-110) routed by time of travel plus intrabasin routing (TT-IBR).

Table 23. VERIFICATION SUMMARY

	1977 Actual Data		1977 (Run 33377) Simulated Data	
	Flow (inches)	Suspended solids (tons)	Flow (inches)	Suspended solids (tons)
JAN.	0.02	0.82	0.005	0
FEB.	1.07	993	0.65	243
MAR.	2.47	1245	2.24	272
APRIL	1.59	692	0.86	142[1]
MAY	0.63	475	0.44	11.4
JUNE	0.042	5.5	0.14	0
JULY	0.63[2]	2958[2]	0.10[2]	0[2]
AUG.	-	-	0.32	0.97
SEPT.	-	-	0.56	365[3]

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1. Fortran error message, underflow, encountered during simulation interval for April 21, 12:45, standard Fortran fix-up taken and simulation continued.

2. Actual record complete through July 10, 1977. Large discrepancy in flow and suspended solids between actual and simulation is due to a large local storm in the eastern Honey Creek basin not recorded at Tiffin gage that was used as precipitation input to NPS model.

3. Simulation complete through Sept. 18, 1977.

and 5th, heavy rains produced a major runoff event, with the highest suspended solids and phosphorus concentrations of the year. The Tiffin gages, however, do not record any major rainfall, and so the model fails to simulate this event altogether. Local observers reported severe, highly localized thundershowers during this period, tracking across the middle of the basin.

It was also apparent that the moisture retained in the soil was greater the first half of 1977, a fact that is reflected by higher base flows and greater sediment production during May and June. The use of a variable K3 might compensate for this condition in part.

SECTION 10

EVALUATION OF BEST MANAGEMENT PRACTICES

The magnitude of diffuse pollutants from agricultural land runoff in the Great Lakes, especially Lake Erie, has been well documented in several recent studies (COE, 1975; GLBC, 1976).

The tributary input of phosphorus from diffuse sources was estimated at 6600 metric tons during 1975, with most of the phosphate mass transport occurring in association with soil particles. It has also been estimated that most of this material originates from agricultural land within the Lake Erie basin, much of which is intensively cultivated, especially in the western portion. Because of physiographic features much of the agricultural land in the western Ohio portion of the basin is flat and poorly drained, but extremely productive under the necessary condition of artifical drainage. The Honey Creek basin is highly representative of the major soil types and drainage conditions, and as shown in Table 3 is 83% agricultural land, with only one small municipal point source. Melmore record shows that the 151 sq. mi. drainage area above the gage discharges 38 M.T./yr. (0.98 kg/ha) of total phosphorus, a value consistent with the major agricultural basins in Lake Erie, which range from 1.1 to 1.4 kg/ha/yr. output.

Given the existence of the land resource data base, one of the tasks accomplished in prior studies was to calculate the potential gross erosion in the basin, by sub-areas, using the land cover, soils and slope file combinations for each of the 12,000 cells, based on the Universal Soil Loss Equation (Stewart, 1975). From this work during 1976 came a prototype report(RMA,1977), which focused on land management techniques and sediment runoff from cultivated lands. It was apparent that in order to influence the local farmers in implementing these practices several steps were necessary; first, in the actual source areas, transport and impact of these pollutants had to be better defined and measured and second, the degree of success in improving water quality (while maintaining productivity) had to be proven, either on an estimated basis by modeling studies or in actual practices by demonstration.

With the calibration of the NPS model for 1976, it was felt that a comparison of the estimated pollutant load reduction by the two methods would be of interest. One potentially successful practice, that of no-till planting, was selected and the NPS model run to reflect the impact of this practice. In the final calibration of NPS for the 1976 data, it was found that very careful specification of land cover, fines accumulation, fines removal and initial fines pool were critical. As calibrated, the output is supply-limited during the high water table period of the year and overland-flow limited during most of the growing season.

NPS MODEL PARAMETER ADJUSTMENT

The NPS model calibrated to Honey Creek for 1976 represents what is hereafter referred to as conventional (cropland) management. As presently formulated, it does not contain explicit provisions for testing alternative farm management scenarios. When calibrated to a watershed as large as Honey Creek, the model represents at a point, the variety of natural processes and management practices that are occurring over a 150 square mile area. Insofar as the fines generation equation of the QUAL subroutine represents a distinct reality, the COVVEC parameter, set on a monthly basis, is the only model parameter that is directly measurable and used as measured. Other model parameters attempt to approximate measurable physical characteristics or process rates but are subject to the model calibration process which can result in large discrepancies between the measured and the calibrated parameter value. The difference in real world values for the parameters and the calibrated values is a rough measure of the discrepancy between actual and model processes.

For example, the parameter INFIL represents an index of the mean soil infiltration rate on the watershed. Its use in NPS attempts to represent a distribution of soil permeability in space but actually results in the simulated infiltration rate being distributed in time as a function of soil wetness. The mean soil infiltration rate of Honey Creek soils is approximately 0.4 in./hr, a value assigned to INFIL for the first calibration run. However, calibration efforts quickly revealed that INFIL must be radically lower than the real world value of 0.4 in./hr: a final value of 0.02 in./hr was eventually selected. Even such an artificially low value was not sufficient to produce the overland flow from pervious areas needed for sediment washoff in the last half of calibration year 1976.

With these observations in mind, it is possible nonetheless to estimate conceptually the direction of change to various NPS model parameters that can be anticipated if a change in cropland management occurs. Table 24 presents a preliminary attempt to do this. Across the top are listed the NPS model parameters in three groups: LANDS (hydrology), QUAL (sediment production), and land use variables. Candidate best management practices are shown down the right. The estimated direction of change in a model parameter due to implementation of a practice is indicated

Table 24. AGRICULTURAL LAND MANAGEMENT PRACTICES versus NON-POINT MODELLING PARAMETERS MODEL PARAMETER IMPACT

PRACTICE	HYDROLOGIC (LANDS)													SEDIMENT (QUAL)						
	UZSN	LZSN	INFIL	INTER	IRC	NN	SS	L	K3	EXPM	KK24	UZS	LZS	JSER	KSER	COVVEC	PMPMAX	ACUPV	REPERV	SRERI
ON-FIELD																				
INTENSITY OF GROUND DISTURBANCE																				
NO-TILL	⇧		⇧			⇧			⬇	⇧		⇧			⬇	⇧	⇧	⬇	⇧	⬇
MINIMUM TILL	⇧		⇧			⇧			⬇	⇧		⇧			⬇	⇧		⬇		
RIDGE PLANT	⇧						⇧	⬇							⇳					
DIRECTION OF GROUND DISTURBANCE																				
CONTOUR							⬇								⬇					
CONTOUR STRIP							⬇								⬇					
TERRACE							⇧	⬇							⇳	⇧				
CROP EFFECTS																				
WINTER COVER										⇧						⇧				
FERTILIZER APPLICATION																	⇧			
CROP ROTATION			⇧												⬇	⇧				
MIXED (FIELD/CHANNEL)																				
IN-FIELD BERMS																				
TILE DRAINS		⬇		⬇	⬇						⬇		⬇							
DIVERSIONS																				
CHANNEL																				
GRASSED WATERWAYS																⇧			⬇	
OUTLET PROTECTION																⇧			⬇	
STREAM BANK PROTECTION																⇧				
SEDIMENT BASINS																		⇧	⬇	

by an arrow. For example, the BMP selected for detailed analysis, no-till, may increase the upper soil zone storage capacity (UZSN) by increasing the organic content of the surface horizon. Infiltration capacity (INFIL) may improve due to minimum disturbance of soil aggregation processes. Surface roughness (NN) will increase due to accumulation of crop residues. The index to actual evapotranspiration (K3) may decrease due to light colored crop and weed residues retarding soil drying. The same residues increase interception storage (EXPM). Depending on the time of year the NPS model simulation is begun, initial upper zone storage may be slightly higher. No-till may have an influence on intrinsic soil erodibility (KRER) but its effect is likely to be complex. No-till may lower the basic capacity of overland flow to carry sediment (KSER) due to its effects on sediment particle size and on surface roughness. Its most obvious and measurable effect is on cover (COVVEC) which is anticipated to increase over conventional tillage every month. Potency factor (PMPMAT) for phosphate is likely to increase due to the limited fertilizer placement options of no-till. Since no-till minimizes soil disturbance, accumulation of fines (ACUPV) during normal plowing seasons will be nearly zero. Undisturbed soil aggregation processes may increase the natural rate of fines removal (REPERV) during non-storm periods. Finally, the initial supply of fines for no-till is likely to be a small fraction of that present under coventional farm management (SRERI).

NPS model parameters can be similarly evaluated for all on-field practices. However, applicability of NPS model to simulate BMP becomes tenuous for mixed field/channel effects such as tile drains or permanent diversions; the NPS model was not designed to simulate BMP's located in the stream channel, although such algorithms are under development. Grassed waterways, stream bank and outlet protection could be treated as practices on critical areas instead of channel practices, but this would require separate NPS model calibration of these partial areas, separate flow and water quality data for which are not likely to be available.

Although it is a fairly straightforward exercise to anticipate the direction of change of a model parameter due to implementation of a BMP, it entirely another matter to select a reasonable value. The first reason for this difficulty is that very few specific field tests have been made of these practices with the NPS model parameters in mind; second, even if such measurements were made and significant changes noted betweem conventional practice and BMP, one would be reluctant to use them as such since most model parameters are "calibrated" and as such bear a fragile and tenuous connection to field measurements. The only notable exception to this is the cover parameter COVVEC which, as mentioned above, is directly measurable in real space and used in the model without modification during calibration.

NPS model simulation

No-till crop production is selected to demonstrate the application of the NPS model to estimation of sediment load reduction by implementation of a potential BMP for several reasons:

1. No-till is a field practice.
2. No-till significantly increases cover (COVVEC).
3. No-till is suitable on signigicant areas of Honey Creek.

No-till crop production in this discussion is limited to row crops, corn and soybeans, which, for Honey Creek in 1976, accounted for 52% of the watershed area. COVVEC, ACUPV and SRERI values for no-till corn and soybeans were estimated. The steps used in the development of no-till scenarios are to determine new model parameter values for no-till, then to run the model for all land uses except row crops, for row crops under conventional management and finally for row corps under no-till management. The monthly suspended solids loads for three no-till scenarios are then calculated by an area-weighted addition of loads from the 3 above NPS model runs.

Suitability for no-till:Three management scenarios

The Ohio Agricultural Research and Development Center has classified major Ohio soil series according to their suitability for no-till corn production (OARDC, 1973). Economic criteria are considered in this classification: corn yields of no-till suitable groups are better, the same, or only slightly lower than yields from conventionally cultivated corn. A computerized count of Honey Creek soils in cropland as they fall into the no-till suitability groups is shown in Table 25. Less than 10% of the watershed is suitable without drainage improvements. Another 25% is suitable if drainage is improved. About fifteen percent of the watershed that is cropland is classified as unsuitable (10.5%) or insufficiently studied to classify (4.4%). Nineteen percent of the watershed is not cropland. The remaining third of the watershed (34.4%) is cropland that can be planted using no-till methods for row crops if excessive soil moisture delays conventional plowing until May 10th or later.

However, due to crop rotation schedules, a field suitable for no-till in any on of the three suitable categories is not always available for no-till row crop production, being committed to wheat or oats during some seasons. Thus the percentage of the watershed potentially available to no-till management in these categories is reduced by approximately three-eights which is the proportion of cropland in 1976 devoted to small grains. These no-till suitability figures are summarized in Table 25 .

The three no-till scenarios for Honey Creek to be examined in detail are derived from Table 25, with the crop rotation re-

Table 25. SUITABILITY OF HONEY CREEK CROPLAND FOR NO-TILL ROW CROP PRODUCTION

No-till suitability class	Percent of Honey Creek Watershed Area	
	Independent of crop rotation schedule	Restriction by crop rotation schedule
Cropland		
Suitable without drainage improvements	6.7	4.2
Suitable only with drainage improvements	25.0	15.6
Suitable only if planting delayed beyond May 10.	34.4	21.5
Not suitable or not yet classified	14.9	-
Other Land Uses		
Urban, woodland, water or wetland	19.0	-

striction, as follows:

No-till Scenario 1: no-till row crop on 4.2% of watershed.
No-till Scenario 2: no-till row crop on 19.8% (4.2%+15.6%)
No-till Scenario 3: no-till row crop on 41.3% (4.2%+15.6%+ 21.5%)

Estimation of no-till parameters

No-till COVVEC values were estimated by the same bookkeeping procedure used for the calibration of the NPS model to all of Honey Creek. Crop rotation effects, prior crop residues, crop area ratios, and conventional practices for small grains were taken into account. Crop residue carryover from previous years and lack of ground disturbance in April and May were the main determinants in the increased COVVEC values estimated for corn and soybeans as shown in Fig. 33. The COVVEC curve for no-till corn is compared to COVVEC values for conventionally tilled row crops (corn and soybeans) in Fig. 34. Although there is some difference in COVVEC between no-till corn and soybean in the last half of the year (Fig. 35), the no-till corn COVVEC values were those used in the no-till NPS scenarios. This choice will not affect the results obtained since there is no overland flow and thus no suspended solids loads simulated from crop land during the last half of the year.

The NPS model permits specification of monthly accumulation rates for soil fines. The ACUPV parameter allows the user to represent soil disturbance, such as plowing, as a daily increase in the pool of soil fines available for washoff. Calibration of the NPS model for Honey Creek in 1976 set this rate at 10 lbs/acre/day for row crops during April and May and during October and November to represent pool increases due to spring and fall plowing activities. Since no-till crop production does not significantly disturb the soil, ACUPV values were reduced to zero for the no-till run of the NPS model.

Similarly, the size of the fines pool (SRERI) in February was reduced from 250 to 25 lbs/acre for the no-till simulation. (Had this reduction not been made, the best no-till scenario would have been nearly indistinguishable from the 1976 conventional simulation).

Simulated erosion control by no-till

In order to estimate suspended solids loads for the three no-till scenarios, the NPS model was run separately for three situations. First, four land uses (small grains, woodland, water/wetland, and urban) with calibration parameter settings were run. Second a one square mile area of row crop, also with calibration parameter settings, was run. Finally, a one square mile area of row crop with cover (COVVEC), fines accumulation rates (ACUPV),

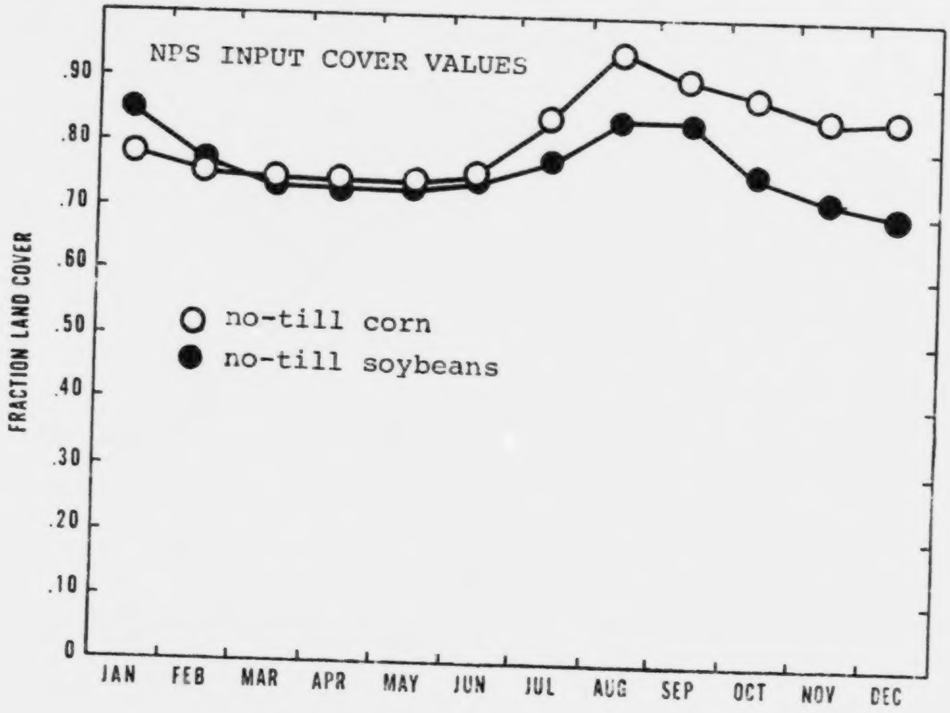

Figure 33. No-till cover values.

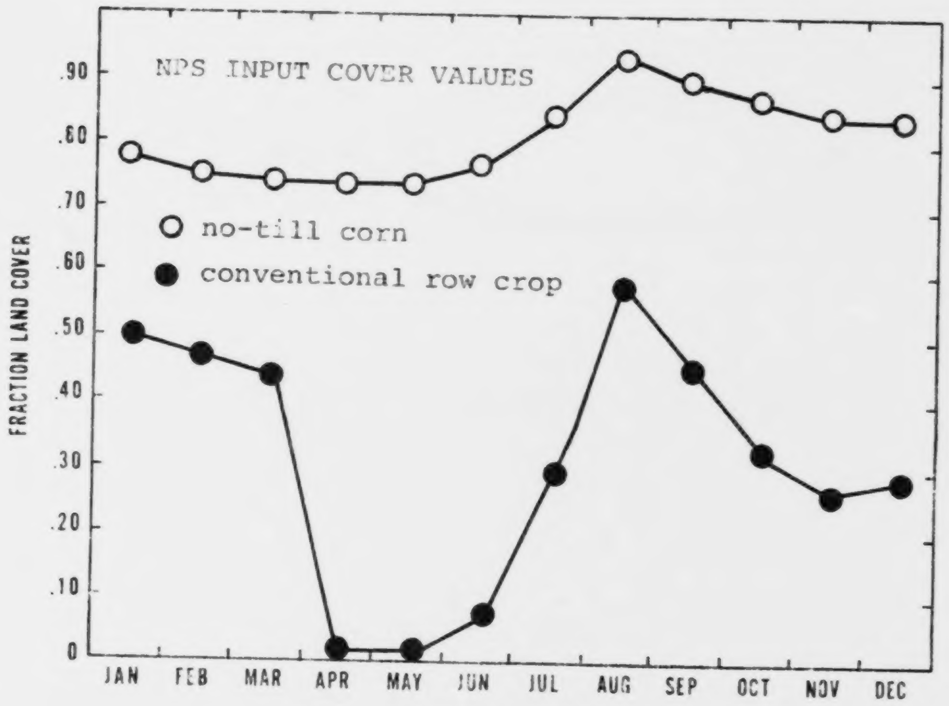

Figure 34. No-till vs. conventional cover values.

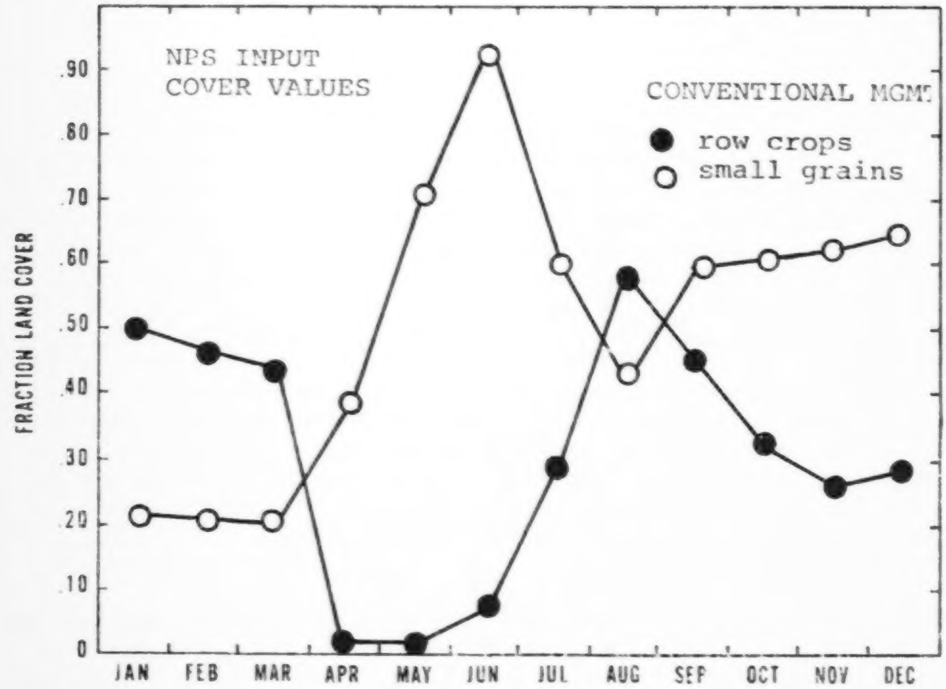

Figure 35. Conventional cover values - row and field crops.

and initial fines (SRERI) modified for no-till (see above) was run. The monthly and annual loads for each scenario were calculated from these three NPS model runs by adding together appropriate proportions of the separate simulations as required by each scenario. The NPS-model-simulated results, summarized in Table 26, predicts that no-till row crop production on well-drained cropland in 1976 could have reduced suspended solids loads by 3%; by 15% if artificial drainage had been improved to the extent possible, and by 33% if row crop planting had been delayed beyond May 10th.

In considering these results, it must be remembered that they apply only to the hydrologic situation of 1976, with its unusual snowmelt-rain event in mid-February. Examination of the monthly results in Table 26 reveals that the three scenarios differ for February, March and April only. Since there was overland flow (simulated) from May through July, the identical results in these months means that the loads generated were not limited by the supply of fines available for washoff but by the depth of overland flow, which was the same in all scenarios. This result is reasonable in light of the relatively mild rainfall experienced during this period; there was no severe late spring or early summer storm to deplete the no-till available fines and thus distinguish it from the conventional management results. The months from August to December were lacking any NPS model overland flow component from pervious surfaces and thus could not deliver sediment to the streams from cropland. The suspended solids simulated during these months is solely from impervious urban surfaces.

Implementation of scenario three is dependent upon a wet spring to delay planting to May 19th. Since this condition does not occur every year in Honey Creek, the long term potential reduction in sediment loads, as predicted by the NPS model for no-till crop production, probably lies somewhere between 15% and 33%.

Although the 15% reduction in sediment load from Honey Creek estimated by the NPS model for no-till row crop production under scenario 2 appears modest, it must be remembered that only 20% of the land area is involved. If a unit area of row crops under conventional management is compared to the same unit area under no-till crop production, it is seen that the simulated delivery of suspended solids from the no-till area is 30% of that from conventionally grown row crops, or a 70% reduction. Other BMP candidates to complement no-till should be evaluated for cropland not suitable for no-till or not in a row crop rotation, possibly by application of the NPS model as illustrated here.

Evaluation of BMP's by the Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE) is another planning tool used to predict soil loss. "C" factors were estimated for

Table 26. EROSION CONTROL BY NO-TILL CROP PRODUCTION IN HONEY CREEK

NPS MODEL SIMULATION
(tons suspended solids)

Month	Conventional Tillage	Crop Rotation Restriction No-till on 4.2%	No-till on 20%	No-till on 41%
Feb.	16,800	16,200	14,100	11,300
Mar.	3,000	2,940	2,680	2,330
Apr.	430	420	380	330
May	500	500	500	500
June	110	110	110	110
July	60	60	60	60
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
Annual Total	21,000	20,300	17,900	14,080
Percent Reduction in Sediment Load		3%	15%	33%

conventional and no-till crop production for Honey Creek (D. Urban, 1978) and applied to the calculation of potential gross erosion rates. While the gross erosion estimate is substantially greater than the actual net transport of sediment from the basin, the relative reduction in USLE and NPS model as results of no-till crop production can be compared (see Table 27).

Each of the 11,500 four hectare cells were calculated using the USLE, based on a "C" factor of 0.245, "L" of 300 feet, "R" of 125 and using the "K" and slope from the computer data base. The no-till improvements to "C" were applied only on that watershed land area where no-till is suitable, (see Table 25). Assuming that the relationship between estimated gross erosion and actual net erosion (i.e., the delivery ratio) holds constant with spatially variable BMPs such as no-till, the percentage reduction comparison shows that the two methodologies of evaluating BMPs would give very different answers (Table 28). The NPS model indicates far less of a reduction in sediment delivery from the basin due to no-till application on suitable lands than does the USLE. It will be an interesting future research effort to compare relative reductions in sediment yields estimated by the NPS model and the USLE for other BMP scenarios.

It should be noted that the USLE estimates a long term gross erosion value and so to be compared directly with the NPS simulation, several years of data should be analyzed. This, of course is not yet possible for the Honey Creek basin, but the comparison shown is informative in terms of the variability to be expected.

Table 27. EFFECT OF NO-TILL as estimated by the USLE

	Total Soil Loss (Tons)	Soil Loss (Tons/acre)	Reduction (%)	Total Soil Loss (w/delivery ratio) 0.0834
Present Conditions C= 0.245	249,237	2.9		20,800
No-till Class I	214,108	3.5	14.1%	17,868
No-till Class I & II	117,219	1.4	53.0%	9,782
No-till Class I, II, IV	66,517	0.8	73.3	5,551

NOTE: Includes 88% of all land area above Melmore; agricultural land, meadow, forest, urban and brush land. Land not included is lacking "K" value, "C" value, or other data in file.

Table 28. COMPARISON OF METHODS FOR BEST MANAGEMENT PRACTICE EVALUATION

NPS MODELLING vs USLE ANALYSIS

Tillage Practice	Estimated Percentage Reduction in Sediment Load	
	NPS Model	USLE
No-till Class I	3%	14.1%
No-till Class I & II	15%	53.0%
No-till Class I, II & IV	33%	73.3%

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APPENDIX A

HONEY CREEK BASIN

LAND RESOURCE INFORMATION SYSTEM

The land resource information system (LRIS) that exists for Honey Creek watershed consists of land use, soil, and slope data recorded and computer-stored for each of 11,600 data points or cells. Other data files include political and hydrologic boundaries in which each of the 11,600 data points is assigned a number corresponding to its location within a political unit or a subbasin in Honey Creek watershed. RMA has developed computer programs that can characterize the whole basin or any political or hydrologic subunit in terms of land use, soil and slope. The utility of the soil information is enchanced by an ancillary soil characteristic data file. With this soil data file any characteristic listed can be selected to characterize any or all spatial subsets of the watershed. Furthermore, other programs convert the statistical characterization of the watershed into a spatial characterization, by sending the stored information to a CALCOMP plotter that produces maps reflecting the characterization selected. To illustrate the flexibility of LRIS and its backup statistical and mapping computer capabilities, Resource Management Associates produced a series of thirteen tables. In this series various characteristics of Honey Creek watershed are summarized for each of 18 subbasins. The subbasins are arranged in a hierarchy from the headwaters to the mouth but the data presented are not cummulative; statistics for a main stem reach refer to that reach only and do not represent the total area above that reach. The subbasins described in the tables are shown on Figure 18. The subbasin numbering on the map and tales correspond. For each characteristic, listed across the top of the table, two entries are shown. For every subbasin, on the left, is given the area, in hectares, that characteristic or co-occurrence of characteristics occurs. On the right is given the percentage of the whole basin that is found in the subbasin and having the listed characteristic. Footnotes are used to amplify certain aspects of the tables.

Table A1. Presents land use in Honey Creek by subbasin. In the table, seven land use categories are shown and represent one aggregation of the 21 land use categories coded for Honey Creek. The summary shows that 50 and 30% of the whole basin are devoted

to row and field (small grain) crops respectively.

Table A2. Displays the distribution of physiographic regions in the subbasins. Ground and end moraine account for nearly 80% of the watershed.

Table A3. Divides the subbasins into slope categories. The basin is quite flat: 77.3% has a slope of 0-2% and another 15.3% has a slope of 2-4%.

Table A4. Shows how the various subbasins occur with respect to county jurisdictions. Overall, more than half of Honey Creek (57.5%) is in Seneca Co.

Table A5. For this table and most of the rest, the ancillary soil characteristic data file was used. Here, each subbasin is statistically described by the drainage characteristics of its soils. Thus, Ackerman Ditch is somewhat to very poorly drained in 1124 of its 1136 hectares. (This representation assumes no artificial drainage).

Table A6. Shows that most (82.1%) of Honey Creek has a seasonal water table that is quite close to the surface (0-0.5 ft.: category 1 + category 2). Not all subbasins are similar however: note subbasins 5 and 6 in water table categories 1 and 2.

Table A7. Illustrates the intrinsic erodibility of Honey Creek soils according to an index (k) developed by SCS. About two thirds of Honey Creek soils have a moderate to moderately high erosion potential (k=0.37 or 0.43).

Table A8. Shows the permeability of cropland soils by subbasin. The table entries show the hectares of land having the stated permeability and the percentage of the total basin area represented.

Table A9. Describes the subbasins soils in terms of their fineness of texture. The table entries reveal the hectares of land in a subbasin that have soils (plow layer) capable of passing stated percentages of their particles through a number 200 sieve.

Table A10. Shows the distribution of plow layer soil textures in the various subbasins. Over 60% of the watershed is covered with silty loam soils.

Table A11. Departs from the format in the previous tables. It lists hectares of crop types by physiographic regions. All the physiographic regions appear similar in the ratio of land devoted to field vs row crops with the exception of glacial drift.

Table A12. OARDC has classified Ohio soils according to their suitability for no-till corpping of continuous corn. Table 12 presents this classification for Honey Creek watershed. It is seen that only 7% is suitable outright and another 28.7% suitable if artificial drainage is provided.

Table A13. Presents the estimation of soil loss in Honey Creek watershed by application of the Universal Soil Loss Equation. The equation was applied to each of the 11,600 points in the data file. The areas subject to levels of erosion in one of five categories were added for each subbasin. Thus Ackerman Ditch (1) had 444 hectares that lost 2-4 tons per acre per year, and 372 hectares losing 4-8 tons/acre/yr. The various assumptions made in the calculation are listed in footnote 3 to the table.

Subbasin code used in Tables A-1--A-3 and A-6--A-10:

```
 1 ACKERMAN DITCH
 2 HONEY CR @ RT 103
 3 HONEY AB BROKNKNF
 4 TRIB AT SCOTT RD
 5 TRIB AT WEIS ROAD
 6 HONEY AB AICHHOLZ
 7 HONEY CR @ RT 4
 8 BROKNKNF @ LINE R
 9 AICHHLZ @ CO R 49
10 HONEY CR AB SILVR
11 SILVR CR AB MARSH
12 SILVR CR BL MARSH
13 SILVR CR AT HONEY
14 HONEY CR @ MELMOR
15 BUCKEYE C @ RT 67
16 HONEY CR @ RT 231
17 MOHAWK @ RT 213
18 HONEY CR @ MOUTH
19 MISSING DATA
-----------------
20 TOTAL ALL BASINS
```

Table A-1. LAND USE IN HONEY CREEK BY SUBBASIN

Land Use Type

	1 ROW CROP		2 FIELD CROP		3 OTHER AG		4 WOODLOT (DECID)		5 WET-LANDS		6 WATER		7 ALL URBAN		8 MISSING DATA		9 TOTAL ALL USES	
SUBBASINS	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%
1 ACKERM	672	1.4	300	0.6	12	0.0	96	0.2	0	0.0	8	0.0	48	0.1	0	0.0	1136	2.4
2 HONEY	1408	3.0	1036	2.2	32	0.1	284	0.6	12	0.0	8	0.0	148	0.3	0	0.0	2928	6.2
3 HONEY	1408	3.0	1072	2.3	16	0.0	208	0.4	4	0.0	28	0.1	136	0.3	0	0.0	2872	6.1
4 TRIB A	400	0.8	352	0.7	0	0.0	96	0.2	12	0.0	4	0.0	12	0.0	0	0.0	876	1.9
5 TRIB A	992	2.1	756	1.6	12	0.0	168	0.4	596	1.3	36	0.1	52	0.1	0	0.0	2612	5.5
6 HONEY	2660	5.6	1572	3.3	40	0.1	660	1.4	12	0.0	36	0.1	212	0.4	0	0.0	5192	11.0
7 HONEY	2032	4.3	1016	2.2	12	0.0	448	1.0	48	0.1	64	0.1	220	0.5	0	0.0	3840	8.1
8 BROKNK	2732	5.8	1588	3.4	36	0.1	508	1.1	12	0.0	72	0.2	360	0.8	0	0.0	5308	11.3
9 AICHHL	2244	4.8	1244	2.6	36	0.1	376	0.8	32	0.1	24	0.1	256	0.5	4	0.0	4216	8.9
10 HONEY	1252	2.7	760	1.6	24	0.1	324	0.7	4	0.0	32	0.1	148	0.3	0	0.0	2544	5.4
11 SILVR	1852	3.9	844	1.8	4	0.0	230	0.6	12	0.0	36	0.1	100	0.2	0	0.0	3128	6.6
12 SILVR	484	1.0	388	0.8	0	0.0	204	0.4	36	0.1	4	0.0	16	0.0	0	0.0	1132	2.4
13 SILVR	956	2.0	620	1.3	8	0.0	312	0.7	56	0.1	28	0.1	76	0.2	0	0.0	2056	4.4
14 HONEY	728	1.5	444	0.9	8	0.0	132	0.3	4	0.0	12	0.0	64	0.1	0	0.0	1392	3.0
15 BUCKEY	772	1.6	500	1.1	8	0.0	120	0.3	20	0.0	8	0.0	20	0.0	0	0.0	1448	3.1
16 HONEY	1576	3.3	1168	2.5	72	0.2	428	0.9	16	0.0	68	0.1	140	0.3	0	0.0	3468	7.4
17 MOHAWK	728	1.5	452	1.0	16	0.0	148	0.3	0	0.0	8	0.0	28	0.1	4	0.0	1384	2.9
18 HONEY	660	1.4	460	1.0	36	0.1	288	0.6	4	0.0	40	0.1	120	0.3	0	0.0	1608	3.4
19 MISSIN	4	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	4	0.0
20 TOTAL	23560	50.0	14572	30.9	372	0.8	5090	10.8	880	1.9	516	1.1	2156	4.6	8	0.0	47144	100.0

Table A-2. PHYSIOGRAPHIC REGIONS IN HONEY CREEK BY SUBBASIN

	Physiographic Region																	
	1 GLACIAL DRIFT		2 FLOOD PLAIN ALLUVIUM		3 GLACIAL OUTWASH TERRACE		4 GROUND MORAINE DISECTED		5 GROUND MORAINE UNDISECT		6 END MORAINE		7 LACUSTRN SED &ORG DEPOSITS		8 MISSING DATA		9 SUBBASIN TOTAL	
SUBBASINS	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%
1 ACKERM	0	0.0	4	0.0	0	0.0	0	0.0	872	1.8	12	0.0	248	0.5	0	0.0	1136	2.4
2 HONEY	0	0.0	316	0.7	0	0.0	516	1.1	412	0.9	1056	2.2	612	1.3	16	0.0	2928	6.2
3 HONEY	0	0.0	252	0.5	0	0.0	1636	3.5	20	0.0	496	1.1	464	1.0	4	0.0	2872	6.1
4 TRIB A	0	0.0	0	0.0	0	0.0	308	0.7	20	0.0	408	0.9	140	0.3	0	0.0	876	1.9
5 TRIB A	0	0.0	0	0.0	0	0.0	148	0.3	204	0.4	812	1.7	1444	3.1	4	0.0	2612	5.5
6 HONEY	0	0.0	0	0.0	36	0.1	64	0.1	2240	4.8	2424	5.1	384	0.8	44	0.1	5192	11.0
7 HONEY	0	0.0	0	0.0	0	0.0	80	0.2	1452	3.1	1700	3.6	604	1.3	4	0.0	3840	8.1
8 BROKNK	0	0.0	0	0.0	0	0.0	1508	3.2	2320	4.9	1060	2.2	400	0.8	20	0.0	5308	11.3
9 AICHHL	0	0.0	0	0.0	0	0.0	164	0.3	3812	8.1	0	0.0	236	0.5	4	0.0	4216	8.9
10 HONEY	136	0.3	0	0.0	516	1.1	744	1.6	428	0.9	716	1.5	0	0.0	4	0.0	2544	5.4
11 SILVR	0	0.0	684	1.5	0	0.0	324	0.7	1400	3.0	704	1.5	0	0.0	16	0.0	3128	6.6
12 SILVR	0	0.0	256	0.5	0	0.0	60	0.1	732	1.6	0	0.0	60	0.1	24	0.1	1132	2.4
13 SILVR	0	0.0	0	0.0	40	0.1	644	1.4	1308	2.8	0	0.0	64	0.1	0	0.0	2056	4.4
14 HONEY	88	0.2	0	0.0	312	0.7	400	0.8	236	0.5	348	0.7	0	0.0	8	0.0	1392	3.0
15 BUCKEY	0	0.0	452	1.0	0	0.0	140	0.3	856	1.8	0	0.0	0	0.0	0	0.0	1448	3.1
16 HONEY	852	1.8	28	0.1	320	0.7	1704	3.6	536	1.1	24	0.1	0	0.0	4	0.0	3468	7.4
17 MOHAWK	88	0.2	0	0.0	0	0.0	1060	2.2	0	0.0	220	0.5	0	0.0	16	0.0	1384	2.9
18 HONEY	776	1.6	0	0.0	0	0.0	744	1.6	68	0.1	0	0.0	0	0.0	20	0.0	1608	3.4
19 MISSIN	0	0.0	0	0.0	0	0.0	4	0.0	0	0.0	0	0.0	0	0.0	0	0.0	4	0.0
20 TOTAL	1940	4.1	1992	4.2	1224	2.6	10248	21.7	16916	35.9	9980	21.2	4656	9.9	188	0.4	47144	100.0

Table A-3. SLOPE OF LAND IN HONEY CREEK BY SUBBASIN

Slope Catagory
and percent(%)

SUBBASINS	1 0-2.0		2 2.1-4.0		3 4.1-6.0		4 6.1-8.0		5 8.1-12.0		6 12.1-16.		7 ABOVE 16		8 MISSING DATA		9 SUBBASIN TOTAL	
	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%
1 ACKERM	1084	2.3	32	0.1	16	0.0	0	0.0	4	0.0	0	0.0	0	0.0	0	0.0	1136	2.4
2 HONEY	1896	4.0	692	1.5	160	0.3	76	0.2	48	0.1	36	0.1	20	0.0	0	0.0	2928	6.2
3 HONEY	2280	4.8	436	0.9	108	0.2	20	0.0	20	0.0	8	0.0	0	0.0	0	0.0	2872	6.1
4 TRIB A	656	1.4	152	0.3	48	0.1	4	0.0	8	0.0	4	0.0	0	0.0	4	0.0	876	1.9
5 TRIB A	2320	4.9	244	0.5	40	0.1	8	0.0	0	0.0	0	0.0	0	0.0	0	0.0	2612	5.5
6 HONEY	3980	8.4	928	2.0	212	0.4	56	0.1	12	0.0	4	0.0	0	0.0	0	0.0	5192	11.0
7 HONEY	3184	6.8	544	1.2	68	0.1	20	0.0	16	0.0	4	0.0	0	0.0	4	0.0	3840	8.1
8 BROKNK	4524	9.6	600	1.3	148	0.3	24	0.1	12	0.0	0	0.0	0	0.0	0	0.0	5308	11.3
9 AICHHL	3672	7.8	376	0.8	92	0.2	16	0.0	36	0.1	12	0.0	12	0.0	0	0.0	4216	8.9
10 HONEY	1376	2.9	728	1.5	264	0.6	64	0.1	64	0.1	20	0.0	28	0.1	0	0.0	2544	5.4
11 SILVR	2312	4.9	612	1.3	120	0.3	48	0.1	20	0.0	4	0.0	8	0.0	4	0.0	3128	6.6
12 SILVR	920	2.0	140	0.3	52	0.1	12	0.0	8	0.0	0	0.0	0	0.0	0	0.0	1132	2.4
13 SILVR	1720	3.6	224	0.5	52	0.1	16	0.0	36	0.1	0	0.0	4	0.0	4	0.0	2056	4.4
14 HONEY	1064	2.3	204	0.4	52	0.1	20	0.0	24	0.1	12	0.0	12	0.0	4	0.0	1392	3.0
15 BUCKEY	1120	2.4	192	0.4	80	0.2	28	0.1	20	0.0	0	0.0	8	0.0	0	0.0	1448	3.1
16 HONEY	2252	4.8	628	1.3	228	0.5	60	0.1	104	0.2	68	0.1	128	0.3	0	0.0	3468	7.4
17 MOHAWK	1168	2.5	156	0.3	36	0.1	0	0.0	8	0.0	12	0.0	4	0.0	0	0.0	1384	2.9
18 HONEY	916	1.9	320	0.7	132	0.3	52	0.1	76	0.2	56	0.1	56	0.1	0	0.0	1608	3.4
19 MISSIN	0	0.0	0	0.0	0	0.0	0	0.0	4	0.0	0	0.0	0	0.0	0	0.0	4	0.0
20 TOTAL	36444	77.3	7208	15.3	1908	4.0	524	1.1	520	1.1	240	0.5	280	0.6	20	0.0	47144	100.0

Table A-4. LOCATION OF HONEY CREEK SUBBASINS BY COUNTY

	1 SENECA COUNTY		2 CRAWFORD COUNTY		3 HURON COUNTY		4 WYANDOT COUNTY		5 MISSING DATA		6 SUBBASIN TOTAL	
SUBBASINS	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%
1 ACKERMAN DITCH	0	0.0	1136	2.4	0	0.0	0	0.0	0	0.0	1136	2.4
2 HONEY CR @ RT 103	0	0.0	2904	6.2	0	0.0	0	0.0	24	0.1	2928	6.2
3 HONEY AB BROKNKNF	0	0.0	2188	4.6	648	1.4	0	0.0	36	0.1	2872	6.1
4 TRIB AT SCOTT RD	0	0.0	876	1.9	0	0.0	0	0.0	0	0.0	876	1.9
5 TRIB AT WEIS ROAD	0	0.0	708	1.5	1904	4.0	0	0.0	0	0.0	2612	5.5
6 HONEY AB AICHHOLZ	5188	11.0	0	0.0	0	0.0	0	0.0	4	0.0	5192	11.0
7 HONEY CR @ RT 4	2644	5.6	0	0.0	1184	2.5	0	0.0	12	0.0	3840	8.1
8 BROKNKNF @ LINE R	1416	3.0	3552	7.5	300	0.6	0	0.0	40	0.1	5308	11.3
9 AICHHLZ @ CO R 49	4212	8.9	0	0.0	0	0.0	0	0.0	4	0.0	4216	8.9
10 HONEY CR AB SILVR	2512	5.3	0	0.0	0	0.0	0	0.0	32	0.1	2544	5.4
11 SILVR CR AB MARSH	608	1.3	2504	5.3	0	0.0	0	0.0	16	0.0	3128	6.6
12 SILVR CR BL MARSH	796	1.7	320	0.7	0	0.0	0	0.0	16	0.0	1132	2.4
13 SILVR CR AT HONEY	2000	4.2	0	0.0	0	0.0	0	0.0	56	0.1	2056	4.4
14 HONEY CR @ MELMOR	1388	2.9	0	0.0	0	0.0	0	0.0	4	0.0	1392	3.0
15 BUCKEYE C @ RT 67	300	0.6	1020	2.2	0	0.0	72	0.2	56	0.1	1448	3.1
16 HONEY CR @ RT 231	3136	6.7	4	0.0	0	0.0	236	0.5	92	0.2	3468	7.4
17 MOHAWK @ RT 213	1376	2.9	0	0.0	0	0.0	0	0.0	8	0.0	1384	2.9
18 HONEY CR @ MOUTH	1508	3.2	0	0.0	0	0.0	0	0.0	100	0.2	1608	3.4
19 MISSING DATA	4	0.0	0	0.0	0	0.0	0	0.0	0	0.0	4	0.0
20 TOTAL ALL BASINS	27088	57.5	15212	32.3	4036	8.6	308	0.7	500	1.1	47144	100.0

Table A-5. SOIL DRAINAGE IN HONEY CREEK BY SUBBASIN

SUBBASINS	1 WELL DR. & MOD. WELL DR.		2 SOMEWHAT POORLY DRAINED		3 POORLY AND VERY POORLY D		4 NON-SOIL		5 MISSING DATA		6 SUBBASIN TOTAL	
	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%
1 ACKERMAN DITCH	12	0.0	468	1.0	656	1.4	0	0.0	0	0.0	1136	2.4
2 HONEY CR @ RT 103	740	1.6	1228	2.6	932	2.0	4	0.0	24	0.1	2928	6.2
3 HONEY AB BROKNKNF	452	1.0	1268	2.7	1100	2.3	0	0.0	52	0.1	2872	6.1
4 TRIB AT SCOTT RD	136	0.3	428	0.9	312	0.7	0	0.0	0	0.0	876	1.9
5 TRIB AT WEIS ROAD	8	0.0	812	1.7	1648	3.5	0	0.0	144	0.3	2612	5.5
6 HONEY AB AICHHOLZ	360	0.8	4248	9.0	580	1.2	0	0.0	4	0.0	5192	11.0
7 HONEY CR @ RT 4	84	0.2	2436	5.2	1192	2.5	0	0.0	128	0.3	3840	8.1
8 BROKNKNF @ LINE R	380	0.8	3068	6.5	1776	3.8	0	0.0	84	0.2	5308	11.3
9 AICHHLZ @ CO R 49	24	0.1	2980	6.3	1084	2.3	124	0.3	4	0.0	4216	8.9
10 HONEY CR AB SILVR	572	1.2	1744	3.7	144	0.3	12	0.0	72	0.2	2544	5.4
11 SILVR CR AB MARSH	332	0.7	1980	4.2	800	1.7	0	0.0	16	0.0	3128	6.6
12 SILVR CR BL MARSH	24	0.1	852	1.8	240	0.5	0	0.0	16	0.0	1132	2.4
13 SILVR CR AT HONEY	168	0.4	1492	3.2	280	0.6	4	0.0	112	0.2	2056	4.4
14 HONEY CR @ MELMOR	416	0.9	804	1.7	164	0.3	0	0.0	8	0.0	1392	3.0
15 BUCKEYE C @ RT 67	308	0.7	788	1.7	256	0.6	0	0.0	56	0.1	1448	3.1
16 HONEY CR @ RT 231	812	1.7	2108	4.5	456	1.0	0	0.0	92	0.2	3468	7.4
17 MOHAWK @ RT 213	136	0.3	1052	2.2	188	0.4	0	0.0	8	0.0	1384	2.9
18 HONEY CR @ MOUTH	612	1.3	808	1.7	88	0.2	0	0.0	100	0.2	1608	3.4
19 MISSING DATA	0	0.0	4	0.0	0	0.0	0	0.0	0	0.0	4	0.0
20 TOTAL ALL BASINS	5576	11.8	28568	60.6	11936	25.3	144	0.3	920	2.0	47144	100.0

Table A-6. DEPTH TO SEASONAL HIGH WATER TABLE

Depth (feet)

	1 0		2 0.1-0.5		3 0.6-1.5		4 1.6-3.0		5 3.1-5.0		6 MORE THAN 5.0		7 NON-SOIL		8 MISSING DATA		9 SUBBASIN TOTAL	
SUBBASINS	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%
1 ACKERM	656	1.4	460	1.0	20	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1136	2.4
2 HONEY	924	2.0	1216	2.6	660	1.4	0	0.0	112	0.2	12	0.0	4	0.0	0	0.0	2928	6.2
3 HONEY	1100	2.3	916	1.9	804	1.7	16	0.0	36	0.1	0	0.0	0	0.0	0	0.0	2872	6.1
4 TRIB A	312	0.7	428	0.9	136	0.3	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	876	1.9
5 TRIB A	1648	3.5	272	0.6	540	1.1	152	0.3	0	0.0	0	0.0	0	0.0	0	0.0	2612	5.5
6 HONEY	580	1.2	4248	9.0	196	0.4	164	0.3	4	0.0	0	0.0	0	0.0	0	0.0	5192	11.0
7 HONEY	1188	2.5	1780	3.8	724	1.5	132	0.3	16	0.0	0	0.0	0	0.0	0	0.0	3840	8.1
8 BROKNK	1776	3.8	2872	6.1	552	1.2	56	0.1	52	0.1	0	0.0	0	0.0	0	0.0	5308	11.3
9 AICHHL	1084	2.3	2980	6.3	0	0.0	24	0.1	4	0.0	0	0.0	124	0.3	0	0.0	4216	8.9
10 HONEY	148	0.3	1740	3.7	160	0.3	452	1.0	32	0.1	0	0.0	12	0.0	0	0.0	2544	5.4
11 SILVR	800	1.7	1980	4.2	332	0.7	0	0.0	16	0.0	0	0.0	0	0.0	0	0.0	3128	6.6
12 SILVR	240	0.5	852	1.8	12	0.0	12	0.0	16	0.0	0	0.0	0	0.0	0	0.0	1132	2.4
13 SILVR	292	0.6	1480	3.1	52	0.1	172	0.4	56	0.1	0	0.0	4	0.0	0	0.0	2056	4.4
14 HONEY	168	0.4	804	1.7	160	0.3	256	0.5	4	0.0	0	0.0	0	0.0	0	0.0	1392	3.0
15 BUCKEY	296	0.6	788	1.7	268	0.6	36	0.1	60	0.1	0	0.0	0	0.0	0	0.0	1448	3.1
16 HONEY	456	1.0	2108	4.5	336	0.7	476	1.0	92	0.2	0	0.0	0	0.0	0	0.0	3468	7.4
17 MOHAWK	188	0.4	1052	2.2	96	0.2	40	0.1	8	0.0	0	0.0	0	0.0	0	0.0	1384	2.9
18 HONEY	88	0.2	808	1.7	268	0.6	344	0.7	100	0.2	0	0.0	0	0.0	0	0.0	1608	3.4
19 MISSIN	0	0.0	4	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	4	0.0
20 TOTAL	11944	25.3	26768	56.8	5316	11.3	2332	4.9	608	1.3	12	0.0	144	0.3	0	0.0	47144	100.0

Table A-7. INTRINSIC ERODIBILITY OF CROPLAND SOILS

Intrinsic Erodibility (K)

	1 .17-.24 (LOW POT EROSION)		2 0.28		3 0.32		4 0.37		5 0.43		6 0.49 (HI POT. EROSION)		7 NON-CROPLAND		8 MISSING DATA		9 SUBBASIN TOTAL	
	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%
1 ACKERM	0	0.0	276	0.6	0	0.0	212	0.4	24	0.1	0	0.0	164	0.3	460	1.0	1136	2.4
2 HONEY	76	0.2	360	0.8	12	0.0	1024	2.2	552	1.2	0	0.0	488	1.0	416	0.9	2928	6.2
3 HONEY	40	0.1	496	1.1	16	0.0	772	1.6	772	1.6	0	0.0	380	0.8	396	0.8	2872	6.1
4 TRIB A	12	0.0	68	0.1	16	0.0	396	0.8	196	0.4	0	0.0	124	0.3	64	0.1	876	1.9
5 TRIB A	0	0.0	44	0.1	264	0.6	156	0.3	660	1.4	0	0.0	864	1.8	624	1.3	2612	5.5
6 HONEY	1516	3.2	280	0.6	144	0.3	564	1.2	1724	3.7	0	0.0	960	2.0	4	0.0	5192	11.0
7 HONEY	1080	2.3	48	0.1	28	0.1	616	1.3	940	2.0	4	0.0	788	1.7	328	0.7	3840	8.1
8 BROKNK	884	1.9	908	1.9	0	0.0	1348	2.9	516	1.1	0	0.0	980	2.1	672	1.4	5308	11.3
9 AICHHL	2476	5.3	8	0.0	8	0.0	980	2.1	8	0.0	0	0.0	732	1.6	4	0.0	4216	8.9
10 HONEY	596	1.3	200	0.4	124	0.3	392	0.8	656	1.4	4	0.0	540	1.1	32	0.1	2544	5.4
11 SILVR	460	1.0	580	1.2	16	0.0	1144	2.4	292	0.6	0	0.0	432	0.9	204	0.4	3128	6.6
12 SILVR	492	1.0	80	0.2	4	0.0	160	0.3	8	0.0	0	0.0	260	0.6	128	0.3	1132	2.4
13 SILVR	992	2.1	56	0.1	12	0.0	440	0.9	44	0.1	4	0.0	452	1.0	56	0.1	2056	4.4
14 HONEY	268	0.6	164	0.3	96	0.2	320	0.7	324	0.7	0	0.0	216	0.5	4	0.0	1392	3.0
15 BUCKEY	188	0.4	216	0.5	8	0.0	440	0.9	260	0.6	0	0.0	148	0.3	188	0.4	1448	3.1
16 HONEY	380	0.8	452	1.0	312	0.7	632	1.3	852	1.8	0	0.0	704	1.5	136	0.3	3468	7.4
17 MOHAWK	28	0.1	124	0.3	112	0.2	180	0.4	732	1.6	0	0.0	200	0.4	8	0.0	1384	2.9
18 HONEY	24	0.1	316	0.7	164	0.3	88	0.2	484	1.0	0	0.0	432	0.9	100	0.2	1608	3.4
19 MISSIN	0	0.0	0	0.0	0	0.0	0	0.0	4	0.0	0	0.0	0	0.0	0	0.0	4	0.0
20 TOTAL	9520	20.2	4676	9.9	1336	2.8	9864	20.9	9048	19.2	12	0.0	8864	18.8	3824	8.1	47144	100.0

Table A-8. PERMEABILITY OF CROPLAND SOILS BY SUBBASIN

Permeability (inches/hour)

SUBBASINS	1 0 HECTARE	%	2 0.1 HECTARE	%	3 0.2 HECTARE	%	4 0.6 HECTARE	%	5 2.0 HECTARE	%	6 > OR = TO 6.3 HECTARE	%	7 NON-CROPLAND HECTARE	%	8 MISSING DATA HECTARE	%	9 SUBBASIN TOTAL HECTARE	%
1 ACKERM	0	0.0	0	0.0	96	0.2	876	1.9	0	0.0	0	0.0	164	0.3	0	0.0	1136	2.4
2 HONEY	0	0.0	0	0.0	36	0.1	2356	5.0	24	0.1	24	0.1	488	1.0	0	0.0	2928	6.2
3 HONEY	0	0.0	0	0.0	84	0.2	1844	3.9	528	1.1	24	0.1	392	0.8	0	0.0	2872	6.1
4 TRIB A	0	0.0	0	0.0	8	0.0	744	1.6	0	0.0	0	0.0	124	0.3	0	0.0	876	1.9
5 TRIB A	0	0.0	0	0.0	164	0.3	620	1.3	960	2.0	4	0.0	864	1.8	0	0.0	2612	5.5
6 HONEY	56	0.1	2388	5.1	1548	3.3	0	0.0	236	0.5	4	0.0	960	2.0	0	0.0	5192	11.0
7 HONEY	8	0.0	944	2.0	1112	2.4	0	0.0	976	2.1	8	0.0	792	1.7	0	0.0	3840	8.1
8 BROKNK	8	0.0	312	0.7	904	1.9	2800	5.9	264	0.6	32	0.1	988	2.1	0	0.0	5308	11.3
9 AICHHL	24	0.1	948	2.0	2480	5.3	0	0.0	28	0.1	0	0.0	732	1.6	4	0.0	4216	8.9
10 HONEY	24	0.1	944	2.0	628	1.3	0	0.0	336	0.7	68	0.1	544	1.2	0	0.0	2544	5.4
11 SILVR	8	0.0	80	0.2	460	1.0	2124	4.5	8	0.0	16	0.0	432	0.9	0	0.0	3128	6.6
12 SILVR	0	0.0	92	0.2	492	1.0	268	0.6	4	0.0	16	0.0	260	0.6	0	0.0	1132	2.4
13 SILVR	20	0.0	384	0.8	1004	2.1	0	0.0	116	0.2	48	0.1	484	1.0	0	0.0	2056	4.4
14 HONEY	16	0.0	668	1.4	284	0.6	0	0.0	200	0.4	4	0.0	220	0.5	0	0.0	1392	3.0
15 BUCKEY	0	0.0	92	0.2	144	0.3	976	2.1	32	0.1	28	0.1	176	0.4	0	0.0	1448	3.1
16 HONEY	44	0.1	1492	3.2	408	0.9	224	0.5	504	1.1	72	0.2	724	1.5	0	0.0	3468	7.4
17 MOHAWK	48	0.1	952	2.0	48	0.1	0	0.0	128	0.3	4	0.0	200	0.4	4	0.0	1384	2.9
18 HONEY	20	0.0	724	1.5	24	0.1	0	0.0	308	0.7	44	0.1	488	1.0	0	0.0	1608	3.4
19 MISSIN	0	0.0	4	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	4	0.0
20 TOTAL	276	0.6	10024	21.3	9924	21.1	12832	27.2	4652	9.9	396	0.8	9032	19.2	8	0.0	47144	100.0

Table A-9. DISTRIBUTION OF FINE TEXTURED SOILS ON CROPLAND
Percent of cropland soil passing No. 200 sieve

	1		2		3		4		5		6		7		8		9	
	0 - 30 COARSE SOILS		31 - 60		61 - 70		71 - 80		81 - 90		91 - 100 FINE SOILS		NON-CROPLAND		MISSING DATA		SUBBASIN TOTAL	
SUBBASINS	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%
1 ACKERM	4	0.0	12	0.0	0	0.0	0	0.0	120	0.3	836	1.8	164	0.3	0	0.0	1136	2.4
2 HONEY	76	0.2	32	0.1	24	0.1	36	0.1	1364	2.9	908	1.9	468	1.0	0	0.0	2928	6.2
3 HONEY	40	0.1	0	0.0	4	0.0	0	0.0	1848	3.9	588	1.2	392	0.8	0	0.0	2872	6.1
4 TRIB A	0	0.0	0	0.0	0	0.0	0	0.0	588	1.2	164	0.3	124	0.3	0	0.0	876	1.9
5 TRIB A	276	0.6	8	0.0	0	0.0	0	0.0	784	1.7	680	1.4	864	1.8	0	0.0	2612	5.5
6 HONEY	4232	9.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	960	2.0	0	0.0	5192	11.0
7 HONEY	2072	4.4	4	0.0	0	0.0	0	0.0	664	1.4	308	0.7	792	1.7	0	0.0	3840	8.1
8 BROKNK	1160	2.5	28	0.1	12	0.0	4	0.0	2064	4.4	1052	2.2	988	2.1	0	0.0	5308	11.3
9 AICHHL	3480	7.4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	732	1.6	4	0.0	4216	8.9
10 HONEY	2000	4.2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	544	1.2	0	0.0	2544	5.4
11 SILVR	552	1.2	8	0.0	8	0.0	16	0.0	1852	3.9	260	0.6	432	0.9	0	0.0	3128	6.6
12 SILVR	604	1.3	0	0.0	0	0.0	0	0.0	156	0.3	112	0.2	260	0.6	0	0.0	1132	2.4
13 SILVR	1572	3.3	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	484	1.0	0	0.0	2055	4.4
14 HONEY	1172	2.5	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	220	0.5	0	0.0	1392	3.0
15 BUCKEY	292	0.6	0	0.0	8	0.0	0	0.0	840	1.8	132	0.3	176	0.4	0	0.0	1448	3.1
16 HONEY	2520	5.3	4	0.0	0	0.0	0	0.0	176	0.4	44	0.1	724	1.5	0	0.0	3468	7.4
17 MOHAWK	1180	2.5	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	200	0.4	4	0.0	1384	2.9
18 HONEY	1120	2.4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	488	1.0	0	0.0	1608	3.4
19 MISSIN	4	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	4	0.0
20 TOTAL	22356	47.4	96	0.2	56	0.1	56	0.1	10456	22.2	5084	10.8	9032	19.2	8	0.0	47144	100.0

Table A-10. TEXTURE OF CROPLAND SOILS IN HONEY CREEK

	1 SILTY LOAM		2 SILT/SND CLAY LOAM		3 LOAM		4 MUCK AND PEAT		5 SANDY LOAM		6 SILTY CLAY		7 LOAMY FINE SAND		8 NON-CROP NON-SOIL &NO DATA		9 SUBBASIN TOTAL	
SUBBASINS	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%
1 ACKERM	420	0.9	536	1.1	0	0.0	4	0.0	12	0.0	0	0.0	0	0.0	164	0.3	1136	2.4
2 HONEY	1600	3.4	672	1.4	48	0.1	52	0.1	44	0.1	0	0.0	0	0.0	512	1.1	2928	6.2
3 HONEY	1904	4.0	520	1.1	12	0.0	16	0.0	4	0.0	0	0.0	0	0.0	416	0.9	2872	6.1
4 TRIB A	576	1.2	176	0.4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	124	0.3	876	1.9
5 TRIB A	924	2.0	536	1.1	4	0.0	272	0.6	8	0.0	0	0.0	4	0.0	864	1.8	2612	5.5
6 HONEY	3572	7.6	416	0.9	216	0.5	0	0.0	0	0.0	24	0.1	0	0.0	964	2.0	5192	11.0
7 HONEY	2100	4.5	900	1.9	24	0.1	0	0.0	4	0.0	0	0.0	12	0.0	800	1.7	3840	8.1
8 BROKNK	3480	7.4	748	1.6	16	0.0	4	0.0	40	0.1	0	0.0	0	0.0	1020	2.2	5308	11.3
9 AICHHL	2580	5.5	848	1.8	36	0.1	0	0.0	0	0.0	16	0.0	0	0.0	736	1.6	4216	8.9
10 HONEY	1524	3.2	88	0.2	320	0.7	0	0.0	40	0.1	0	0.0	0	0.0	572	1.2	2544	5.4
11 SILVR	2504	5.3	124	0.3	44	0.1	0	0.0	8	0.0	0	0.0	0	0.0	448	1.0	3128	6.6
12 SILVR	768	1.6	84	0.2	4	0.0	0	0.0	0	0.0	0	0.0	0	0.0	276	0.6	1132	2.4
13 SILVR	1204	2.6	160	0.3	144	0.3	0	0.0	24	0.1	16	0.0	0	0.0	508	1.1	2056	4.4
14 HONEY	876	1.9	100	0.2	196	0.4	0	0.0	0	0.0	0	0.0	0	0.0	220	0.5	1392	3.0
15 BUCKEY	1168	2.5	52	0.1	20	0.0	0	0.0	4	0.0	0	0.0	0	0.0	204	0.4	1448	3.1
16 HONEY	1968	4.2	212	0.4	480	1.0	12	0.0	0	0.0	0	0.0	0	0.0	796	1.7	3468	7.4
17 MOHAWK	840	1.8	156	0.3	176	0.4	0	0.0	0	0.0	4	0.0	0	0.0	208	0.4	1384	2.9
18 HONEY	784	1.7	64	0.1	220	0.5	8	0.0	0	0.0	0	0.0	0	0.0	532	1.1	1608	3.4
19 MISSIN	4	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	4	0.0
20 TOTAL	28796	61.1	6392	13.6	1960	4.2	368	0.8	188	0.4	60	0.1	16	0.0	9364	19.9	47144	100.0

Table A-11. DISTRIBUTION OF ROW AND FIELD CROPS BY PHYSIOGRAPHIC REGION

Region	Row crops		Field crops		Other land uses		Missing data		Total for region	
	Hectare	%	Hectare	%	Hectare	%	Hectare	%	Hectare	%
1. Glacial drift	624	1.3	672	1.4	644	1.4	0	0.0	1940	4.1
2. Flood plain alluvium	888	1.9	688	1.5	416	0.9	0	0.0	1992	4.2
3. Glacial outwash terrace	560	1.2	332	0.7	332	0.7	0	0.0	1224	2.6
4. Ground moraine disected	5240	11.1	3148	6.7	1860	3.9	0	0.0	10248	21.7
5. Ground moraine undisected	9048	19.2	5052	10.7	2816	6.0	0	0.0	16916	35.9
6. End moraine	4940	10.5	3408	7.2	1632	3.5	0	0.0	9980	21.2
7. Lacustrn sed. and org. Deposits	2160	4.6	1224	2.6	1272	2.7	0	0.0	4656	9.9
8. Missing data	100	0.2	48	0.1	32	0.1	8	0.0	188	0.4
9. Subbasin total	23560	50.0	14572	30.9	9004	19.1	8	0.0	47144	100.0

Table A-12. SUITABILITY OF CROPLAND FOR NO-TILL CORN PRODUCTION

SUBBASINS	1 SUITABLE HECTARE	1 SUITABLE %	2 SUITABLE IF DRAINED HECTARE	2 SUITABLE IF DRAINED %	3 NOT SUITABLE HECTARE	3 NOT SUITABLE %	4 SUITABLE IF LATE PLANTING HECTARE	4 SUITABLE IF LATE PLANTING %	5 SOIL NOT CLASSIFD HECTARE	5 SOIL NOT CLASSIFD %	6 NON-CROPLAND HECTARE	6 NON-CROPLAND %	7 MISSING DATA HECTARE	7 MISSING DATA %	8 SUBBASIN TOTAL HECTARE	8 SUBBASIN TOTAL %
1 ACKERMAN DITCH	12	0.0	108	0.2	16	0.0	820	1.7	16	0.0	164	0.3	0	0.0	1136	2.4
2 HONEY CR @ RT 103	612	1.3	692	1.5	40	0.1	788	1.7	284	0.6	488	1.0	24	0.1	2928	6.2
3 HONEY AB BROKNKNF	408	0.9	984	2.1	364	0.8	552	1.2	148	0.3	392	0.8	24	0.1	2872	6.1
4 TRIB AT SCOTT RD	132	0.3	324	0.7	84	0.2	200	0.4	12	0.0	124	0.3	0	0.0	876	1.9
5 TRIB AT WEIS ROAD	104	0.2	592	1.3	48	0.1	640	1.4	364	0.8	864	1.8	0	0.0	2612	5.5
6 HONEY AB AICHHOLZ	56	0.1	2156	4.6	392	0.8	1432	3.0	192	0.4	960	2.0	4	0.0	5192	11.0
7 HONEY CR @ RT 4	116	0.2	916	1.9	472	1.0	1416	3.0	120	0.3	792	1.7	8	0.0	3840	8.1
8 BROKNKNF @ LINE R	324	0.7	1024	2.2	912	1.9	1630	4.0	148	0.3	988	2.1	32	0.1	5308	11.3
9 AICHHLZ @ CO R 49	20	0.0	112	0.2	740	1.6	2604	5.5	4	0.0	732	1.6	4	0.0	4216	8.9
10 HONEY CR AB SILVR	272	0.6	924	2.0	84	0.2	612	1.3	80	0.2	544	1.2	28	0.1	2544	5.4
11 SILVR CR AB MARSH	300	0.6	1090	2.3	560	1.2	694	1.5	56	0.1	432	0.9	16	0.0	3128	6.6
12 SILVR CR BL MARSH	8	0.0	76	0.2	160	0.3	580	1.2	32	0.1	260	0.6	16	0.0	1132	2.4
13 SILVR CR AT HONEY	100	0.2	208	0.4	148	0.3	1012	2.1	80	0.2	484	1.0	24	0.1	2056	4.4
14 HONEY CR @ MELMOR	172	0.4	608	1.3	92	0.2	268	0.6	32	0.1	220	0.5	0	0.0	1392	3.0
15 BUCKEYE C @ RT 67	268	0.6	398	0.8	240	0.5	288	0.6	60	0.1	176	0.4	28	0.1	1448	3.1
16 HONEY CR @ RT 231	252	0.5	1632	3.5	224	0.5	456	1.0	108	0.2	724	1.5	72	0.2	3468	7.4
17 MOHAWK @ RT 213	36	0.1	948	2.0	124	0.3	36	0.1	32	0.1	200	0.4	8	0.0	1384	2.9
18 HONEY CR @ MOUTH	124	0.3	732	1.6	16	0.0	43	0.1	156	0.3	488	1.0	44	0.1	1608	3.4
19 MISSING DATA	0	0.0	4	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	4	0.0
20 TOTAL ALL BASINS	3316	7.0	13508	28.7	4716	10.0	14316	30.4	1924	4.1	9032	19.2	332	0.7	47144	100.0

Table A-13a. POTENTIAL EROSION HAZARD: CROPLAND PRACTICES TYPE ONE
Estimated soil loss (tons/acre/year) L=500', C=0.42

SUBBASINS	1 0-1		2 1-2		3 2-4		4 4-8		5 >8		6 NON-CROPLAND		7 MISSING DATA		8 SUBBASIN TOTAL	
	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%
1 ACKERMAN DITCH	0	0.0	0	0.0	276	0.6	204	0.4	32	0.1	164	0.3	460	1.0	1136	2.4
2 HONEY CR @ RT 103	0	0.0	20	0.0	592	1.3	484	1.0	928	2.0	488	1.0	416	0.9	2928	6.2
3 HONEY AB BROKNKNF	0	0.0	0	0.0	472	1.0	1024	2.2	600	1.3	380	0.8	396	0.8	2872	6.1
4 TRIB AT SCOTT RD	0	0.0	8	0.0	128	0.3	328	0.7	220	0.5	124	0.3	68	0.1	876	1.9
5 TRIB AT WEIS ROAD	0	0.0	0	0.0	304	0.6	476	1.0	344	0.7	864	1.8	624	1.3	2612	5.5
6 HONEY AB AICHHOLZ	0	0.0	36	0.1	1400	3.0	1460	3.1	1332	2.8	960	2.0	4	0.0	5192	11.0
7 HONEY CR @ RT 4	0	0.0	0	0.0	1024	2.2	1060	2.2	640	1.4	788	1.7	328	0.7	3840	8.1
8 BROKNKNF @ LINE R	0	0.0	32	0.1	1440	3.1	1540	3.3	644	1.4	980	2.1	672	1.4	5308	11.3
9 AICHHLZ @ CO R 49	0	0.0	0	0.0	1968	4.2	1216	2.6	296	0.6	732	1.6	4	0.0	4216	8.9
10 HONEY CR AB SILVR	0	0.0	0	0.0	388	0.8	612	1.3	972	2.1	540	1.1	32	0.1	2544	5.4
11 SILVR CR AB MARSH	0	0.0	24	0.1	660	1.4	1044	2.2	760	1.6	432	0.9	208	0.4	3128	6.6
12 SILVR CR BL MARSH	0	0.0	20	0.0	324	0.7	288	0.6	112	0.2	260	0.6	128	0.3	1132	2.4
13 SILVR CR AT HONEY	0	0.0	8	0.0	708	1.5	576	1.2	252	0.5	452	1.0	60	0.1	2056	4.4
14 HONEY CR @ MELMOR	0	0.0	0	0.0	236	0.5	624	1.3	308	0.7	216	0.5	8	0.0	1392	3.0
15 BUCKEYE C @ RT 67	0	0.0	16	0.0	320	0.7	448	1.0	328	0.7	148	0.3	188	0.4	1448	3.1
16 HONEY CR @ RT 231	0	0.0	0	0.0	636	1.3	948	2.0	1044	2.2	704	1.5	136	0.3	3468	7.4
17 MOHAWK @ RT 213	0	0.0	24	0.1	260	0.6	584	1.2	308	0.7	200	0.4	8	0.0	1384	2.9
18 HONEY CR @ MOUTH	0	0.0	8	0.0	288	0.6	244	0.5	536	1.1	432	0.9	100	0.2	1608	3.4
19 MISSING DATA	0	0.0	0	0.0	0	0.0	0	0.0	4	0.0	0	0.0	0	0.0	4	0.0
20 TOTAL ALL BASINS	0	0.0	196	0.4	11424	24.2	13160	27.9	9660	20.5	8864	18.8	3840	8.1	47144	100.0

Table A-13b. POTENTIAL EROSION HAZARD: CROPLAND PRACTICES TYPE TWO
Estimated soil loss (tons/acre/year) L=300', C=0.245

	1 0-1		2 1-2		3 2-4		4 4-8		5 >8		6 NON-CROPLAND		7 MISSING DATA		8 SUBBASIN TOTAL	
SUBBASINS	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%	HECTARE	%
1 ACKERMAN DITCH	0	0.0	332	0.7	156	0.3	12	0.0	12	0.0	164	0.3	460	1.0	1136	2.4
2 HONEY CR @ RT 103	24	0.1	656	1.4	508	1.1	588	1.2	248	0.5	488	1.0	416	0.9	2928	6.2
3 HONEY AB BROKNKNF	0	0.0	552	1.2	1020	2.2	384	0.8	140	0.3	380	0.8	396	0.8	2872	6.1
4 TRIB AT SCOTT RD	8	0.0	156	0.3	320	0.7	136	0.3	64	0.1	124	0.3	68	0.1	876	1.9
5 TRIB AT WEIS ROAD	0	0.0	372	0.8	460	1.0	228	0.5	64	0.1	864	1.8	624	1.3	2612	5.5
6 HONEY AB AICHHOLZ	260	0.6	1376	2.9	1432	3.0	930	1.9	260	0.6	960	2.0	4	0.0	5192	11.0
7 HONEY CR @ RT 4	80	0.2	1132	2.4	992	2.1	432	0.9	88	0.2	788	1.7	328	0.7	3840	8.1
8 BROKNKNF @ LINE R	124	0.3	1628	3.5	1392	3.0	396	0.8	116	0.2	980	2.1	672	1.4	5308	11.3
9 AICHHLZ @ CO R 49	268	0.6	2108	4.5	852	1.8	200	0.4	52	0.1	732	1.6	4	0.0	4216	8.9
10 HONEY CR AB SILVR	64	0.1	388	0.8	620	1.3	572	1.2	328	0.7	540	1.1	32	0.1	2544	5.4
11 SILVR CR AB MARSH	116	0.2	668	1.4	1060	2.2	472	1.0	172	0.4	432	0.9	208	0.4	3128	6.6
12 SILVR CR BL MARSH	80	0.2	336	0.7	244	0.5	64	0.1	20	0.0	260	0.6	128	0.3	1132	2.4
13 SILVR CR AT HONEY	164	0.3	652	1.4	508	1.1	164	0.3	56	0.1	452	1.0	60	0.1	2056	4.4
14 HONEY CR @ MELMOR	16	0.0	316	0.7	592	1.3	168	0.4	76	0.2	216	0.5	8	0.0	1392	3.0
15 BUCKEYE C @ RT 67	24	0.1	376	0.8	416	0.9	184	0.4	112	0.2	148	0.3	188	0.4	1448	3.1
16 HONEY CP @ RT 231	12	0.0	716	1.5	952	2.0	540	1.1	408	0.9	704	1.5	136	0.3	3468	7.4
17 MOHAWK @ RT 213	24	0.1	312	0.7	592	1.3	184	0.4	64	0.1	200	0.4	8	0.0	1384	2.9
18 HONEY CR @ MOUTH	8	0.0	296	0.6	284	0.6	276	0.6	212	0.4	432	0.9	100	0.2	1608	3.4
19 MISSING DATA	0	0.0	0	0.0	0	0.0	0	0.0	4	0.0	0	0.0	0	0.0	4	0.0
20 TOTAL ALL BASINS	1272	2.7	12372	26.2	12400	26.3	5900	12.5	2496	5.3	8864	18.8	3840	8.1	47144	100.0

APPENDIX B

PRECIPITATION RECORDS

Table B-1. PRECIPITATION COMPARISION BETWEEN TIFFIN HOURLY AND DAILY (1976)

Day	January		February		March		April	
	Daily*	Hourly	Daily*	Hourly	Daily*	Hourly	Daily*	Hourly
1			T				0.05	0.1
2	T	0.3	0.04		T	0.3	0.25	0.3
3	0.20				0.22	0.3		0.1
4	0.01				0.79	1.0		
5				0.4	0.68		0.04	
6			0.80				T	.01
7	0.11	0.2	T					
8	0.11		T					
9			T					
10					0.13			
11	0.11	0.1			T		0.11	0.1
12	T				0.14			0.1
13		0.9			0.01			
14	0.86							
15								
16	0.02		0.05	2.0	0.17			
17	0.02		1.81		0.14			
18			0.02	0.1	T	NO DATA		
19		0.1	0.06		T			
20	0.14	0.1	.01		T		0.09	0.1
21	0.14		T	0.5	0.35		0.12	0.3
22	0.07		0.54	0.1	T		0.12	
23	T		0.03				T	
24							0.07	0.1
25		0.8			0.09		0.49	0.7
26	1.41	0.6	T				0.26	0.2
27	0.02							
28	T				0.25			
29	0.02	0.1						
30	0.08	0.1			T			
31	0.11				0.15			
Totals	3.43	3.3	3.36	3.1	3.12		1.60	2.1

Table B-1. (cont.)

Day	May Daily	May Hourly	June Daily	June Hourly	July Daily	July Hourly	August Daily	August Hourly
1			0.13	0.5	0.31	0.2	0.01	
2	0.1	0.1	0.47	0.1	0.21			
3	0.09	0.1						
4	T							
5								
6	0.1	1.1					T	0.8
7	1.10					0.4	0.94	0.6
8	T				1.35	0.8	0.36	
9					T		0.04	
10								
11			T					
12	0.01		0.02				0.02	0.4
13		0.1					0.74	0.5
14	T	0.1						0.1
15	0.22	0.1			T		0.03	
16	0.08	0.2	0.13	0.4	0.1	0.4	T	
17	0.7	1.4	0.31		0.15			
18	0.9			0.4				
19	T		0.69	0.3				
20			0.01					
21	0.03				0.2	0.2		
22			T	0.1	0.06	0.3		
23			0.26		0.96	0.6		
24			0.18	0.9	0:4	0.4		
25			0.63		T			
26	T						T	
27					0.15	0.2	0.01	0.1
28		0.1		0.2		0.1	0.02	0.4
29	0.04	0.6	0.20		0.04		0.71	
30	0.69	0.2	0.06	0.5	T			
31	0.28	0.2						
TOTALS	4.25	4.3	3.09	3.4	3.84	3.6	2.88	2.9

Table B-1. (cont.)

Day	Sept. Daily	Sept. Hourly	Oct. Daily	Oct. Hourly	Nov. Daily	Nov. Hourly	Dec. Daily	Dec. Hourly
1		0.1			T	NO DATA	T	NO DATA
2	0.09	0.6*					0.04	
3							0.04	
4							0.11	
5					T		T	
6			0.11	0.3	T			0.3
7			0.40				0.33	
8					0.01			
9		0.4	T	0.2			T	
10	0.45	0.1	0.26				T	
11	0.07				0.02			
12					T			
13								
14								
15								
16	T	0.6						
17	0.59	0.2						
18	0.27							
19				0.3				
20	0.49	0.6	0.42	0.4			0.22	0.3
21			0.22				0.06	
22	0.01				T			
23				0.1	T			
24	0.02		0.25	0.2	T			
25			0.06		0.01			
26	0.13	0.6			0.13		T	0.2
27	0.51	0.1			0.30		0.16	
28	0.08						0.02	
29					T		0.01	
30				0.4			T	0.1
31			0.40	0.1			0.10	
Totals	2.71	3.3	2.12	2.0	0.47		1.09	0.9

Table B-2. PRECIPITATION COMPARISION BETWEEN TIFFIN HOURLY AND DAILY (1977)

Day	Jan.		Feb.		March	
	Daily	Hourly	Daily	Hourly	Daily	Hourly
1	T		T		T	
2	0.01		T			
3	0.03	0.1	0.09			0.3
4	0.01		0.06	0.3	0.36	0.4
5			0.25		0.25	
6			T			
7	0.08					
8	T				T	
9	0.2					
10	0.47	0.3				
11	0.05					
12	0.01			0.2		0.5
13			0.20		0.61	0.1
14	T		T	0.1	0.04	
15	T		0.03			
16	0.02		T			
17						0.2
18	0.02				1.22	1.3
19	0.02	0.1			0.21	
20	T		T		0.23	0.2
21	T		T		T	
22	0.03				0.52	0.7
23					0.31	
24	T		0.05	0.1		
25	0.02		0.06			
26	0.02	0.1		0.5		
27	0.03		0.93	0.5		0.3
28	0.18	0.1	T		0.94	0.5
29	0.03				0.20	
30						
Total	1.03	0.9	1.67	1.7	4.89	4.5

Table B-3. COMPARISION OF PRECIPITATION RECORDS FOR MARCH, 1976, BETWEEN TIFFIN DAILY AND FREMONT HOURLY RECORDS

	Tiffin	Fremont
March 1		.05
2	T	.30
3	0.22	.07
4	0.79	.91
5	0.68	.30
6		
7		
8		
9		
10	0.13	.12
11	T	
12	0.14	.05
13	0.01	
14		
15		
16	0.17	.24
17	0.14	
18	T	
19	T	
20	T	.17
21	0.35	
22	T	
23		
24		
25	0.09	.15
26		
27		.17
28	0.25	
29		.17
30	T	
31	0.15	.15
	3.12	2.85

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